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A laboratory and field investigation into the discharge characteristics of an experimental flood alleviation scheme on the River Roding in Essex

UNIVERSITY OF BRISTOL
DEPARTMENT OF CIVIL ENGINEERING

A LABORATORY AND FIELD INVESTIGATION INTO THE DISCHARGE CHARACTERISTICS OF AN EXPERIMENTAL FLOOD ALLEVIATION SCHEME ON THE RIVER RODING IN ESSEX

by
D. J. Searle

Thesis Submitted for the degree of Ph.D
in the University of Bristol

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September 1986

MEMORANDUM

The accompanying dissertation, entitled "A Laboratory Investigation into the Discharge Characteristics of an Experimental Flood Alleviation Scheme on the River Roding in Essex", is submitted for the degree of Doctor of Philosophy in the Faculty of Engineering at the University of Bristol.

The dissertation is based upon independent work by the author, while funded by Thames Water Authority, between October 1983 and September 1986. The research was carried out in the Department of Civil Engineering and was supervised by Dr R.H.J. Sellin.

The work and ideas recorded are original except where acknowledged in the text or by reference.

This dissertation has not previously been submitted, in part or whole, for a degree or diploma of any other University or examining body.

Signed

DJSearle

D.J. Searle

September 1986

ACKNOWLEDGEMENTS

I would like to thank Thames Water Authority for their financial support towards the investigation reported in this thesis and for supplying field data on the River Roding.

I would like to thank my supervisor, Dr. R.H.J. Sellin, for his assistance and advice. My thanks also go to Dr. J. Davis for his willingness to give assistance and continued support throughout the project. Mr. P. Leonard lent a valuable and experienced hand in the technical design and construction of much of the apparatus and my thanks go to him for making my aspirations a reality.

ABSTRACT

An investigation was carried out to determine the stage-discharge characteristics of a meandering compound channel with vegetated floodplains. The fundamental interaction mechanism between a main channel and its floodplain was also investigated.

Field and model studies provided the data for this thesis. A stretch of the River Roding in Essex was monitored for the field study and a scale model of a short reach of the river was reproduced in the laboratory. A Froudian model was constructed with vertical and horizontal scales of 16:1 and 50:1 respectively.

Field date over a two year period were used to match the model to the river. The response of the river to proposed changes was then predicted by varying roughness and shaped parameters within the model. To do this, stage discharge curves were determined for the model and scaled up to prototype conditions. Detailed velocity traverses were carried out across selected sections of the model to determine discharge proportions between floodplain and main channel for different depths of floodplain flow.

A computerised data collection facility was developed to assist the model study.

Vegetation density and distribution on the floodbanks of compound rivers, such as the River Roding investigated here, can have a significant effect on total discharge capacity. Over 40% increase in maximum discharge capacity was realised in the abovementioned scheme between heavily vegetated and cleared floodplains. Sever meanders of the floodplain boundaries produced large form roughness, resulting in flow separation on some bends and a reduction in the effective width of the floodplain. Removal of these, requiring relatively small excavation of the floodbanks, could significantly improve the carrying capacity of the river. The discharge in the main channel was reduced at overbank conditions due to the shear

interaction between floodplain flow and main channel flow. Manning roughness coefficients were calculated for particular vegetative conditions of the river. A proposal was made to incorporate a correction factor into calculations of discharge in compound rivers with meandering main channels. The correction factor would be applied to the discharge calculated for an equivalent compound channel without meander. It depended on the degree of meander, or sinuosity, of the main channel, roughness ratio between main channel and floodplain, and depth of flow.

CONTENTS

NOTATION

A - cross-sectional area
Ap - floodplain flow cross-sectional area
Am - main channel cross-sectional area
%ASF - percentage of apparent shear force to total shear force on main channel boundaries
B - half section width in prismatic compound channels with symmetric floodplains or full section width in prismatic compound channels with one floodplain
b - half main channel width for symmetric compound channels or full width in prismatic compound channels with one floodplain
b_p - width of wooded floodplain
b_{fl} - width of floodplain
C - Chezy roughness coefficient
d - depth of flow
g - gravitational acceleration
h - main channel depth
H - total depth of water in main channel
k - effective roughness height
[L] - dimension of length
M - scale ratio   prototype value/model value
M_q - discharge ratio
M_v - velocity ratio
M_d - depth ratio
M_b - length ratio
M_{So} - bed slope ratio
[M] - dimension of mass
n - Manning roughness coefficient
P - wetted perimeter
Q - discharge
ΔQ - change in discharge
$\%\Delta Q$ - percentage change in discharge
Qp - floodplain discharge
Qm - main channel discharge
Q'c - isolated main channel discharge
Q'f - isolated floodplain discharge
R - hydraulic radius
Rf - floodplain hydraulic radius
Rc - main channel hydraulic radius
Re - Reynolds number $4VR/\nu$
Se - friction slope
So - bed slope
s - sinuosity = floodplain bed slope/main channel bed slope
T - equivalent wetted perimeter
[T] - dimension of time
V - mean velocity
Vc - main channel mean velocity
Vfp - floodplain mean velocity
ΔV - (Vc-Vfp)
V^* - shear velocity $\sqrt{gRSo}$
V^*crit-critical shear velocity
α - B/b dimensionless width ratio
β - n(fp)/n(mc) roughness ratio floodplain/main channel

β - (H-h)/H dimensionless depth ratio
δ - b/h aspect ratio of main channel
ϕ - 'n'/'n' bankfull, 'n' calculated by single channel method
ϕc - discharge correction factor for isolated floodplain discharge
ϕf - correction factor for isolated main channel discharge
λ - friction factor 8gRSo/V
λi - ratio of avge shear stress across fluid boundary to avge channel shear stress
λv - i for a vertical interface
λd - i for a diagonal interface
λh - i for a horizontal interface
τ - average bed shear stress ρgRSo
τa - apparent mean shear stress
τav - apparent mean shear stress - vertical interface
τad - apparent mean shear stress - diagonal interface
τah - apparent mean shear stress - horizontal interface
τo - undisturbed floodplain shear stress
τf - average floodplain boundary shear stress
τc - average main channel boundary shear stress
θ - inclination of division lines from horizontal
ν - kinematic viscosity of water
ω - unit weight of water
ρ - density of water

CHAPTER 1

Introduction

River flooding is a common occurrence in the United Kingdom during the wet winter months and the cost effectiveness of flood prevention measures is beginning to be appreciated. This is especially so in rivers flowing through low lying urban areas where considerable damage to property could occur in a flood situation.

An investigation into the flow characteristics of the River Roding Flood Alleviation Scheme has been funded by Thames Water Authority (TWA), with the assistance of the S.E.R.C.. It is one of two pilot schemes currently in operation in the Thames catchment, designed to alleviate flooding in urban and agricultural areas.

With the introduction of the Water Act 1973 and Land Drainage Act 1976, water authorities have had an increased responsibility to maintain or improve their rivers. Furthermore, they have an obligation to minimise disruption to the environment in discharging their duties. In his paper on the "Conservation Aspects of Two River Improvement Schemes in the River Thames Catchment" (49), Weeks emphasised the responsibilities water authorities have with regard to their rivers. He quotes from section 22 of the Water Act;

"In formulating or considering any proposals... these authorities shall have regard to the desirability of preserving natural beauty, of conserving flora, fauna and geological or physiographical features of special interest... and shall take into account any effect which the proposals would have on any such flora, fauna..."

Thames Water Authority, therefore, accepts amongst other duties, the management role of maintaining the tributaries of the River Thames. Some of them, unable to contain high flows experienced mainly during the winter months, consequently overtop their banks and flood adjacent land. The River Roding is just such a river and has a long history of flooding. As an indication of the potentially high cost of flood damage, an estimated £1 million worth, at present day prices, was caused after severe flooding in November 1974, according to Wojcik, in his dissertation "An Experimental Scheme on the River Roding" (50).

The long accepted method for solving river flooding has been channelisation. That is, the realignment and reshaping of a river to form a straight channel with a uniform cross-section and an even bed slope. However, as discussed by Wojcik, although channelisation offeres a low cost solution and has low land requirements, it has a detrimental effect on the ecology of a river, especially on unspoiled rural rivers. It has been argued by Keller and Brookes (48), that to maintain a balanced morphology, natural features such as meanders, pools and riffles, overhanging banks and riverside vegetation need to be preserved, which is not the case in channelisation.

Therefore, in 1979, Thames Water Authority embarked upon an experimental scheme on the River Roding to investigate a means of reducing the frequency of flooding along a particular stretch of it. This involved the excavation of floodways along a 3 km stretch of the river below the village of Abridge in Essex. The aim of the scheme was to provide a two stage, or compound, channel designed to pass high flows of a specified return period without causing flooding of low lying fields and village developments adjacent to the river and minimise the disruption to the environment.

1.1 Experimental Scheme on the River Roding

In the Roding Flood Alleviation Scheme, the lower part of the natural channel was left, as far as possible, unaltered and extra flow capacity was obtained by excavating berms above the mean summer flow on one or both sides of the river to form a wide flood channel or floodway. The compound channel was to provide protection against floods of a 1:70 year return period for the village of Abridge, which was sited at the upstream end of the test section, and a 1:30 year return period for surrounding agricultural land. See figure 1.1 for a plan of the Flood Alleviation Scheme.

To achieve these standards, Wojcik stated that 1200 metres of channel from Abridge downstream would have to be designed to withstand a 1:70 year flood and the remaining 2000 metres designed to a 1:30 year standard.

Wojcik produced the following design discharges ;

1:70 year flood = 50 cumecs
1:30 year flood = 40 cumecs

From this, and from other physical factors involved, he calculated that to contain a 50 cumec discharge, the berm would need to be 30 metres wide and for 40 cumecs, 25 metres wide. In both cases the maximum depth of flow on the berm was assumed to be 1.35 metres.The main channel was assumed trapezoidal with 1:1 side slopes, a total

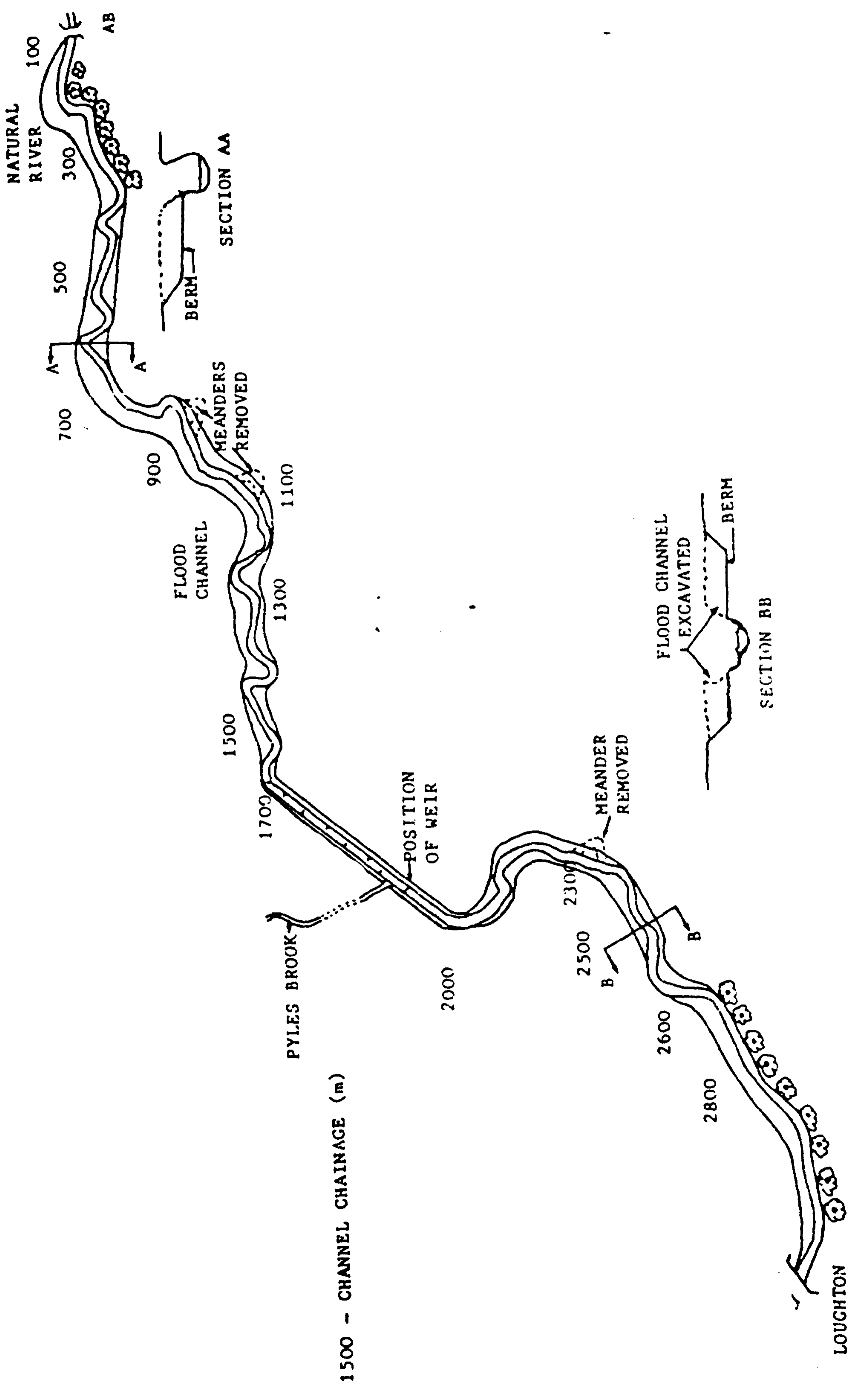


Figure 1.1
Plan of River Roding Flood Alleviation Scheme with
Chainages Marked on and Increasing in Downstream Direction

perimeter of 8 metres and average depth of 0.65 metres. Mannings 'n' values of 0.045 and 0.032 for the main channel and floodplain respectively were used.

Excavation works were carried out during 1979 with the reconfigured river ready for the winter flows of 1979/1980.

Late completion of seeding and topsoiling the floodberms resulted in poor grass cover there at the time of the high winter flows. About 80% of the grass and topsoil was washed off the berms and some scouring of the subsoil occurred. The berms were hydraulically reseeded in 1980.

By 1983, however, it had become apparent that the scheme was not operating as designed. Whatever the causes, the vegetation growing on the flood berm had become far too coarse and large to be grazed. The main channel was overbank more often than the expected 70 days per year. So, a densely vegetated and often waterlogged floodplain was becoming a problem in the maintenance of the river as it needed to be cleared every year at not inconsiderable expense to the Water Authority.

It was decided therefore, that a more detailed study of the experimental reach, or at least a part of it, would be beneficial not only in identifying the problems emerging on the River Roding but also increase the understanding of compound river reaches with vegetated floodplains.

1.2 Project Aims

A short section has been included here setting out the aims of the research project.

Field Investigation

The stage-discharge characteristics of part of the River Roding Flood Alleviation Scheme would be constructed. Particular attention would be paid to peak flows. These would be gauged at predetermined river cross-sections to determine the distribution of flow velocity across the floodplain and in the main channel.

The effect on total discharge capacity of seasonal vegetation growth on the berms of the river would be assessed.

Model Investigation

It was intended to reproduce in a laboratory model, the known behaviour of the Flood Alleviation Scheme from data recorded in the field studies.

Once the model had been matched to the river, the investigation would proceed by varying conditions within it, simulating changes in the field, and observing their effect on the discharge capacity of the reach.

A final objective was to investigate the more fundamental interaction between a meandering main channel with its adjacent floodplains when in the overbank condition.

1.3 General Assumptions regarding Uniform Flow

It is relevant at this point to set out a basic assumption that has been made regarding the flow conditions in the river and laboratory model.

It has been assumed that flow in both cases is uniform and steady. Strictly speaking, uniform flow is not possible as river and model sections vary down their length. Model discharges will be steady but river discharges are unlikely to be so. However, river flows, varying at a rate of less than 0.2 cumecs per hour have been taken as steady. To permit an analysis of the river and model flows, these assumptions have had to be made. Steady non-uniform flow is treated as in this thesis as uniform flow.

1.4 Layout of Thesis

In this section, the author has presented a brief description of the contents of the following chapters to assist the reader in establishing the layout of the thesis.

Chapter two introduces, in some detail, past laboratory work on compound opens channels of simple geometries. It highlights the lack of work carried out to date on the more natural case of meandering compound channels. Chapters three and four describe the design and construction of the laboratory model. A description of the apparatus and associated computer software which the author developed to collect the model data is included. Chapter five details the field study carried out on the Roding and the methods and problems

encountered in measuring river discharges and water levels. Field data between 1984 and 1986 are presented and analysed. Stage discharge curves are produced to provide the input for proving the laboratory model which is covered in chapter six. The roughness materials used, problems encountered in modelling the river flows and stage-discharge curves are presented in chapter six.
Chapter seven deals with all the different roughness configurations of the model, simulating given field conditions. An analysis of all the data is given in chapter 8 and presents conclusions of the model study and a proposal for calculating discharges in compound rivers with meandering main channels using existing laboratory data to provide the correction factors. Chapter nine summarises the conclusions arrived at in chapter 8 and proposes avenues of future research.

CHAPTER 2

Past Research Into Compound Open Channels

To gain an insight into what laboratory experimentation was needed during the investigation, it was necessary to evaluate earlier related work. Here a survey of relevant past literature is presented and the findings arranged, in most cases, in chronological order.

Formulae to predict open channel resistance have been developed and reworked for nearly 100 years. The results have been the emergence of two widely accepted equations using either a constant roughness coefficient 'n' or a variable friction factor 'λ' dependent on a variety of parameters.

The first, commonly referred to as the Manning equation states:

$$V = R^{\frac{2}{3}} S_e^{\frac{1}{2}}/n \qquad (1)$$

where V = the mean section flow velocity

R = the hydraulic radius A/P

P = wetted perimeter of channel

A = cross-section area

S_e = is the friction slope

and n is a roughness value attributed to the bed characteristics.

A more generalised approach used by Chow (5) incorporates a roughness value including major features such as bank waviness and meander of the river, making the total roughness the sum of the individual roughness values.

This method implicitly assumes fully rough flow, i.e. that the flow is independent of Reynolds number. It requires experience and good judgement in estimating values of 'n' in the field.

The second, the Chezy equation states:

$$V = C\sqrt{RS_e} \qquad (2)$$

where

$$C = \sqrt{8g/\lambda} \qquad (3)$$

and λ depends on Reynolds number, hydraulic radius and bed roughness since:

$$1/\sqrt{\lambda} = -c \log\left[\frac{k}{aR} + \frac{b}{Re\sqrt{\lambda}}\right] \qquad (4)$$

The latter method is preferred because it is believed that experimental measurements of friction in open channels over a wide range of conditions are better correlated and understood by the use of λ.

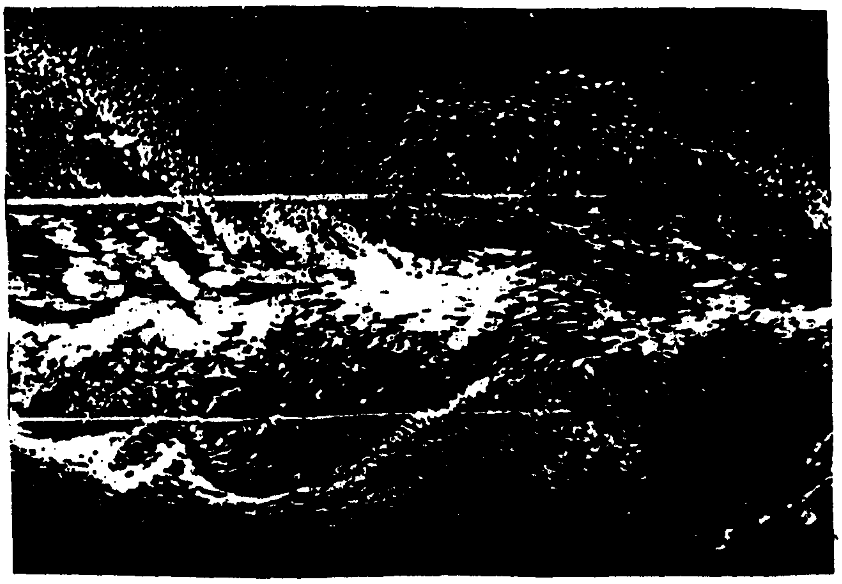
These formulae were developed for channels of relatively simple section and design engineers, on encountering channels of complex section, traditionally split them up into compartments and calculated the conveyance of each separately. The fluid interfaces between compartments were usually ignored in the determination of the wetted perimeter, on the assumption that they would experience no significant shearing forces.

This might be accepted as reasonable when the difference in mean velocities of adjacent compartments was small, but significant interactions occur when the relative submergence of a floodplain to the main channel is small and velocity differences at the interface large.

2.1 Laboratory Evidence of The Kinematic Effect

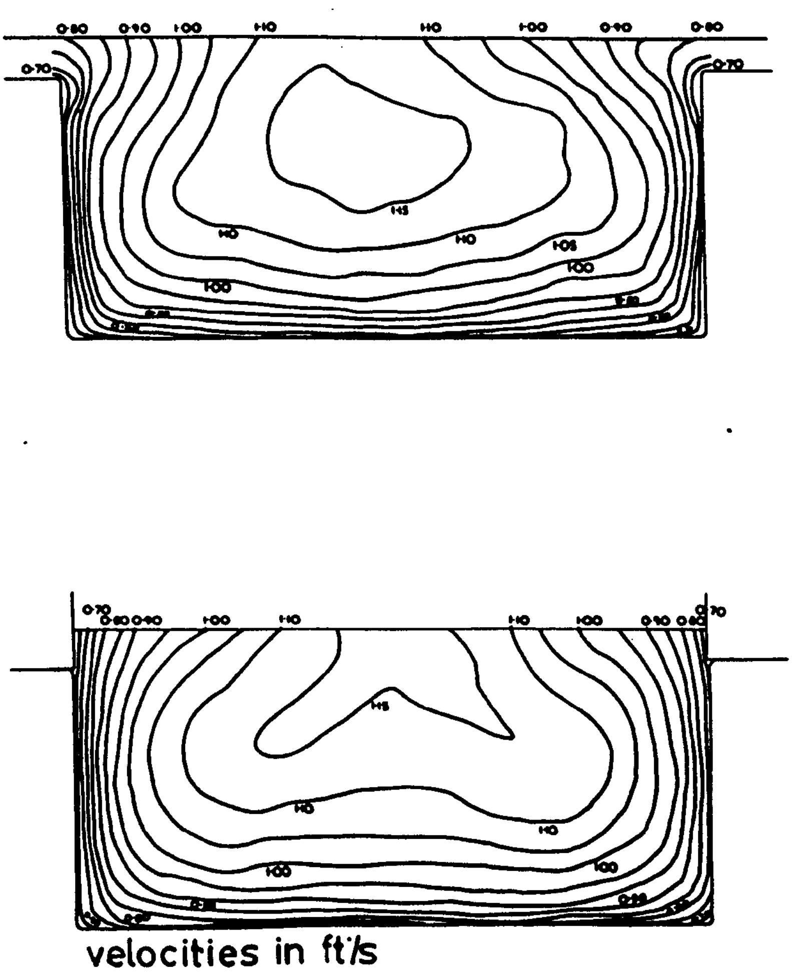
Since Zheleznyakov discovered the "kinematic effect", various researchers have endeavoured to provide more evidence of the phenomenon and to explain it. Some attempts were made to quantify it but until the latter part of the 1970's, most empirical solutions were unsophisticated and approximate. This section reviews the early investigations into compound channel flow.

Zheleznyakov stated that for depths just above bankfull, the interaction of the channel and the floodplain seriously affected the kinematics of the channel stream. This resulted in decreased channel velocities and discharges which were not sufficiently compensated by the increased floodplain velocities and discharges. Barishnikov (2) later confirmed this and found a reduction in the total discharge capacity of up to 16% for flow just above bankfull when compared to the flow obtained in the absence of a floodplain. Sellin(35) revealed evidence of this "kinematic effect", using a laboratory model, by the visualisation of vertically aligned vortices at the channel/floodplain junction as shown in figure 2.1 .



Photograph of flow showing vortices
Figure 2.1 (Sellin)

The photographs were taken with a camera mounted on a carriage over the flume. The speed of the carriage was matched approximately with the speed of the vortex cores which could be seen with aluminium powder, sprinkled on the surface of the water. He also plotted the mean longitudinal velocity distribution for the central region of the channel cross-section with and without the floodplain flow. Figure 2.2 shows the corresponding pair of isovel diagrams.



Isovel diagrams with and without floodplains.

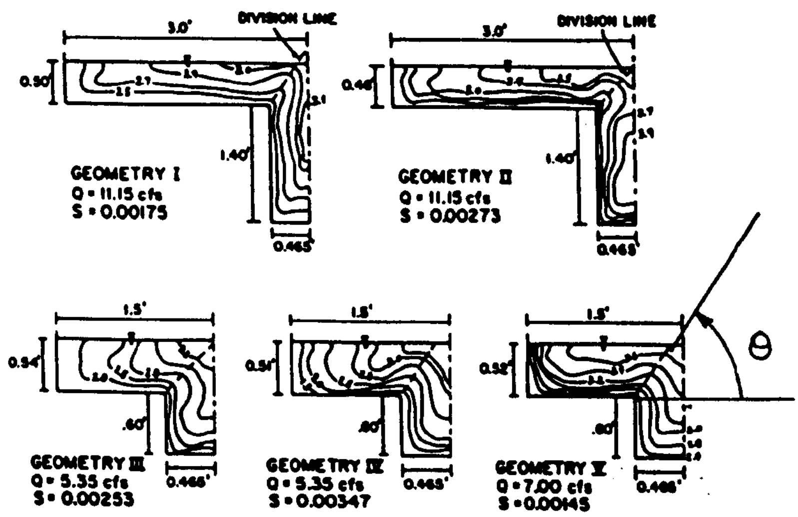
Figure 2.2 (Sellin)

These clearly indicate the presence of the momentum transfer mechanism by the distortion of the isovels due to the strong secondary circulation to the floodplain. Finally, Sellin found that for low overbank depths the discharge could be increased above the interacting condition by isolating the floodplain from the channel with a floodwall. This confirmed the findings mentioned earlier by Zheleznyakov . In 1967, Delleur, Toebes and Udeozo (8) concluded that an interaction was apparent between the main channel and floodplain and that an important factor on the interaction mechanism was the pattern of secondary currents at the interface. Townsend (38) confirmed Sellin's conclusions about the velocity profiles of the compound channel although he used an asymmetric design with one floodplain. He also used dye injection and hot film anemometry to compare the turbulence levels with and without a floodplain. The results showed a marked increase in turbulence, with overbank flow, at the channel/floodplain junction. This work has more recently been extended by Prinos and Townsend (29) in their paper on "Structure of Turbulence in Compound Channel Flows".

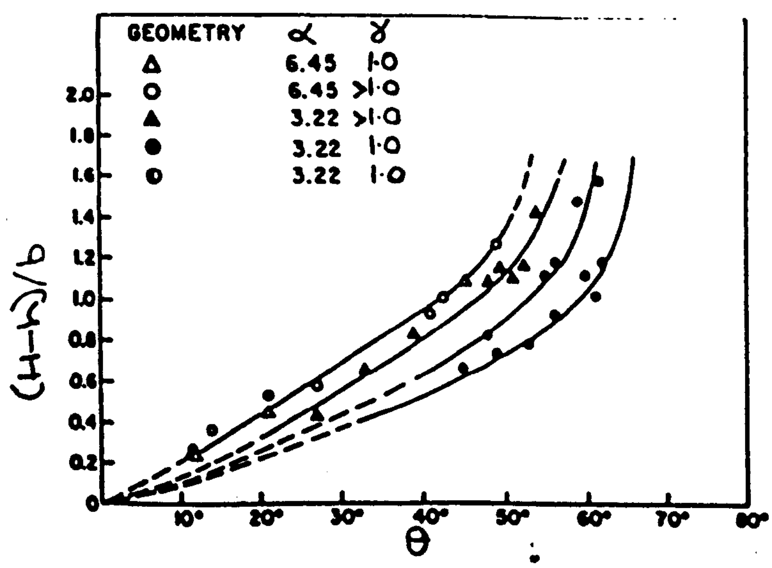
2.2 Quantifying The 'Kinematic Effect' With Modified Friction Factors

A number of attempts were made to predict the stage-discharge curves for overbank flow, either through an artificial variation of the Manning roughness coefficient, or a subdivision of the flow between floodplain and channel with imaginary boundaries and treating the flow for each section separately. Sellin deduced values of Manning's coefficient from his stage-discharge curves. He suggested that with more data, it might be possible to "weight " the roughness factor empirically to allow for the change in flow characteristics.

The trend of research over the years has not generally been in this direction, until very recently. There are, however, a few cases worthy of note from these earlier years. Rice (34) determined the Manning's roughness coefficient for a complex channel at various slopes and roughnesses and demonstrated the errors incurred in the conventional methods of channel analysis, which ignored the presence of the momentum transfer mechanism. A typical textbook analysis like Chow acknowledges the presence of the mechanism and uses both an empirically weighted Manning's roughness coefficient and also the division of flow by imaginary boundaries. Yen and Overton (45) have compared the method of "weighting" the Manning coefficient used by Chow with their own and improved upon it. They analysed the laboratory data produced by Udeozo (39) and were able to locate the planes of approximate zero shear within the compound channel flow (Figure 2.3). They found that with the data available, the plane of zero shear began at the channel/floodplain junction, inclined towards the channel centre-line and the inclination of the plane varied mainly with stage and to a lesser extent on other variables , e.g. roughness distribution (Figure 2.4).

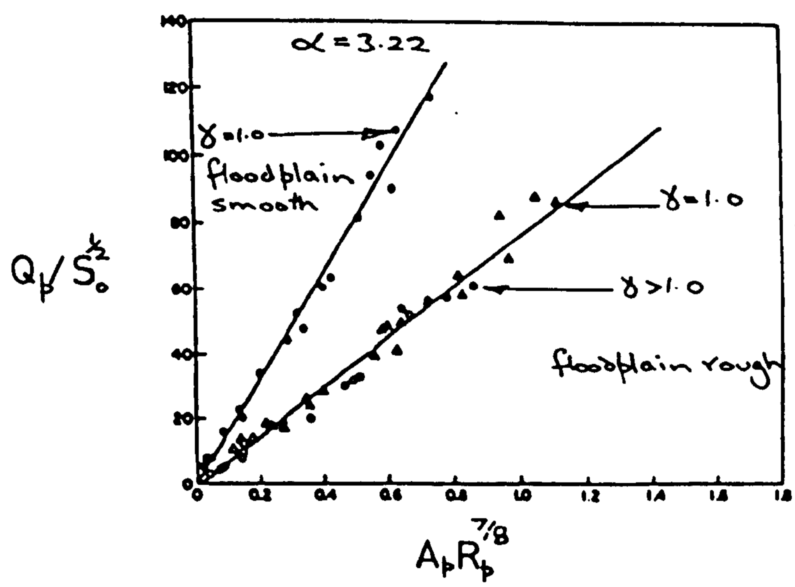


Velocity Contours For Turbulent Flow
From Udeozo's Data (Yen and Overton)
Figure 2.3

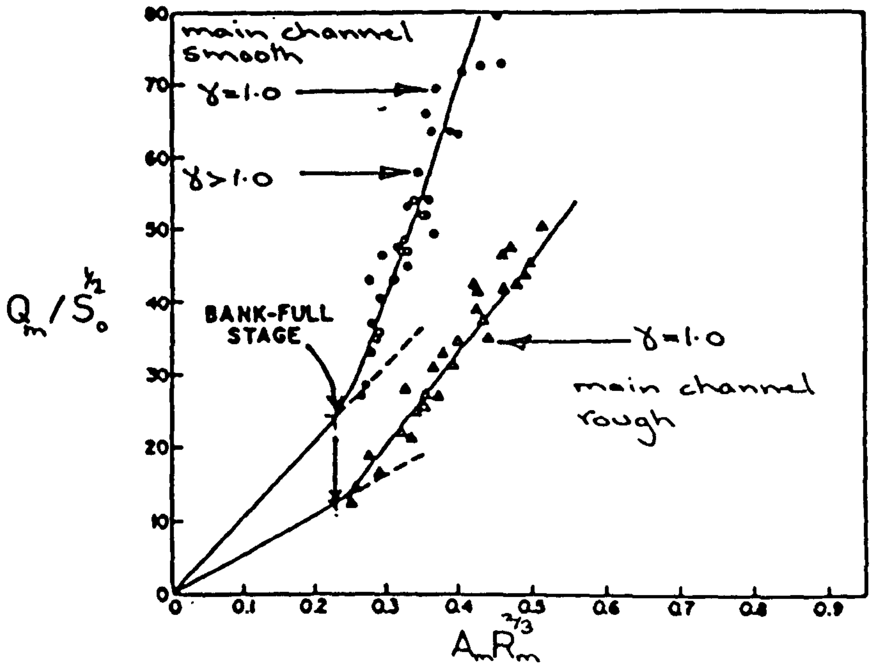


Inclination of Division lines (Yen and Overton)
Figure 2.4

From this, they produced a modified stage-discharge formula based on figures 2.5 and 2.6, which was equivalent to Manning's equation with an effective roughness coefficient. This they compared to the "weighted" Manning equation proposed by Chow (Figure 2.7).

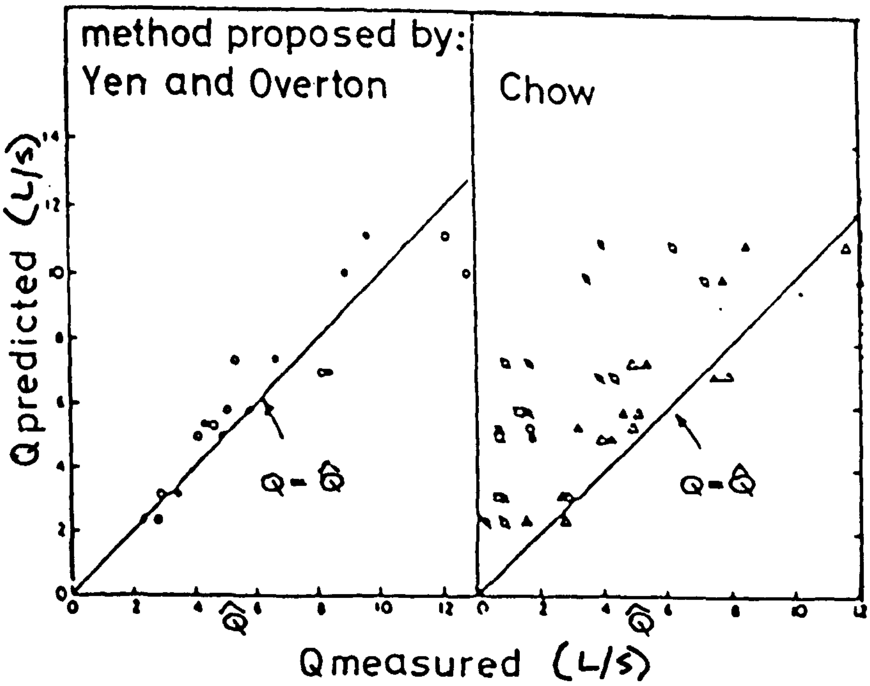


Modified stage -discharge curve for floodplain only
(Yen and Overton)
Figure 2.5



Stage-discharge curve for main channel only (Yen and Overton)

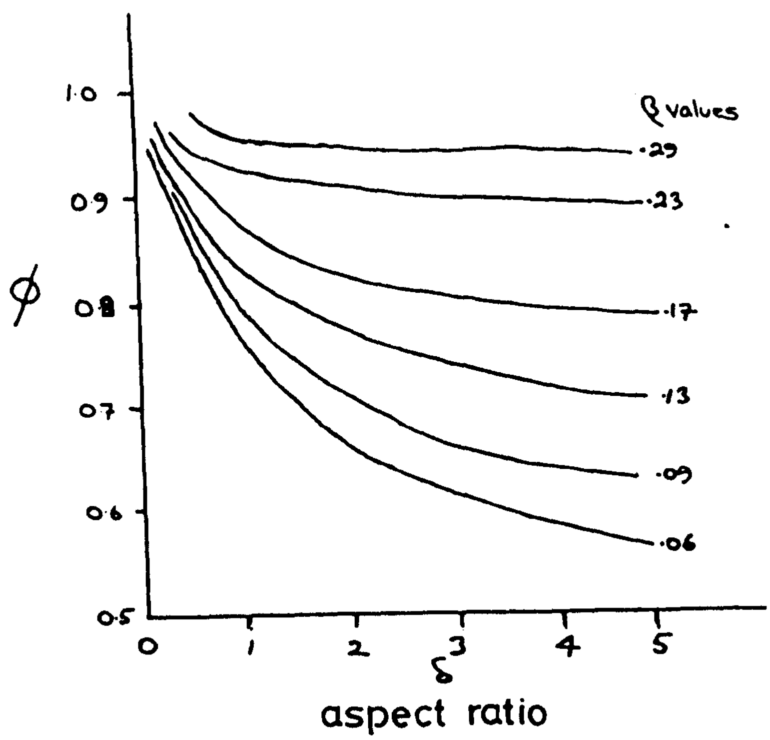
Figure 2.6



Comparison of Discharge Calculation Methods (Yen and Overton)

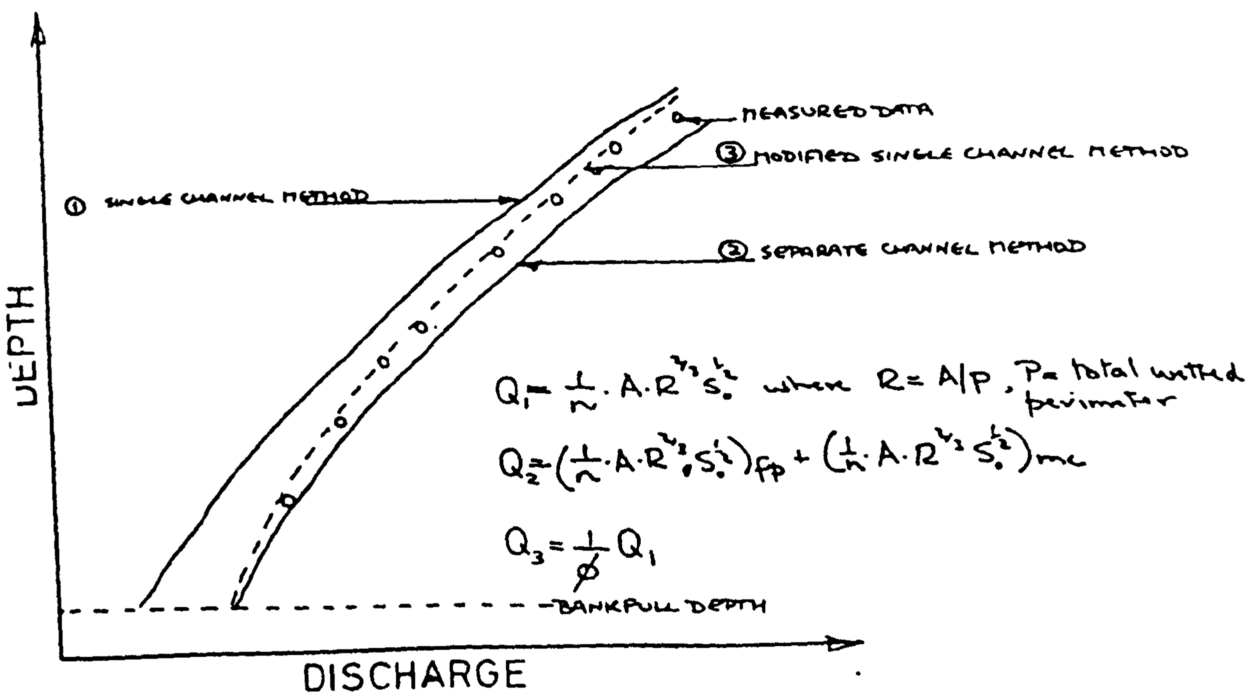
Figure 2.7

James and Brown (15), in research carried out between 1974 and 1976, calculated Manning's n values with the stage-discharge data from their laboratory tests. The n values computed by the single channel method exhibited a decrease just above bankfull stage which compensated for the sudden decrease in hydraulic radius. They produced a set of correction factors, ϕ =n/n(bankfull), with respect to aspect ratio, δ, and relative depth, β, (see figure 2.8) to calculate discharge by a modified single-channel method. From this it was possible to calculate the stage-discharge curves, Figure 2.9. The improvement in the calculation from the standard methods is apparent.



ϕ Ratios Against Aspect Ratio for Various Depth Factors (James and Brown)

Figure 2.8



Depth-Discharge Curves using Various Methods (James and Brown)

Figure 2.9

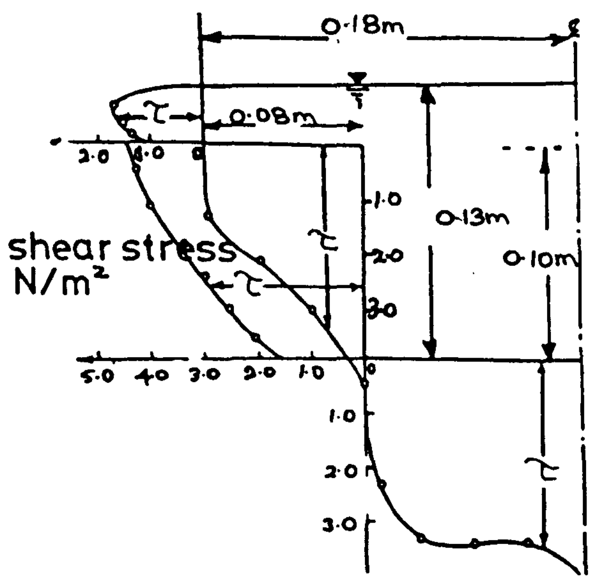
Myers, more recently,(22) investigated the relationship of friction factors to Reynolds number ratios between main channel and floodplain flows. He suggested that the way forward for discharge calculation in compound channels could be to utilise traditional flow formulae whilst incorporating accurate friction factor data.

Apart from the cases mentioned above, research has tended to favour the more traditional method of splitting the flow with an imaginary interface at the floodplain/channel junction and using friction factors based on bed roughness. The method of sub-division and inclusion or otherwise of the interface in the wetted perimeter was generally not the same for the different analyses of the various researchers.

Typical analyses by Chow and Henderson (13) take a vertical interface between channel and floodplain but ignore the interface in calculating the wetted perimeter. This is acceptable for high overbank flows but for the lower cases where interboundary shear is very high, another solution has to be found. Posey (27), in 1967, presented permutations of vertical, diagonal (inclined 45 degrees to the horizontal from the floodplain/channel junction towards the centre-line of the channel) and horizontal interfaces for subdividing the flow. He did not consider very low overbank depths, ranging from ξ = 0.14, to a fairly high overbank condition of ξ = 0.67. He obtained his best agreements with measured discharge values by including the wetted perimeter in the vertical case for the main channel, up to ξ = 0.24. For values of ξ above this he found the single channel method produced the best comparison. The aspect ratio, δ, of his model was 5. Wright and Carstens (44) in 1970, suggested a more refined solution after laboratory tests on air flow in a T-shaped closed conduit. They proposed 1) that for the main channel, the interface be included in the wetted perimeter and 2) the mean shear force along the interface be calculated and incorporated as a propulsive force on the floodplain. It is worth mentioning that in carrying out these experiments, Wright and Carstens could measure the boundary skin friction in the conduit and hence calculate quite accurately the shear force across the floodplain/channel interface.

2.3 Development of The Apparent Shear Force

Ghosh and Jena (12) in 1971, published a paper on compound channels which included the measurement of local boundary shear stresses. Measurement of boundary shear had been well established since Preston (28), 1954, published his paper on the determination of turbulent skin friction in air. Little work had been done in water due to the difficulty in measuring accurately the low pressures involved and none on compound channels had been carried out before 1971. The main results of their work were to demonstrate the non-uniformity of boundary shear stresses (Figure 2.10) and point other researchers towards this line of investigation.

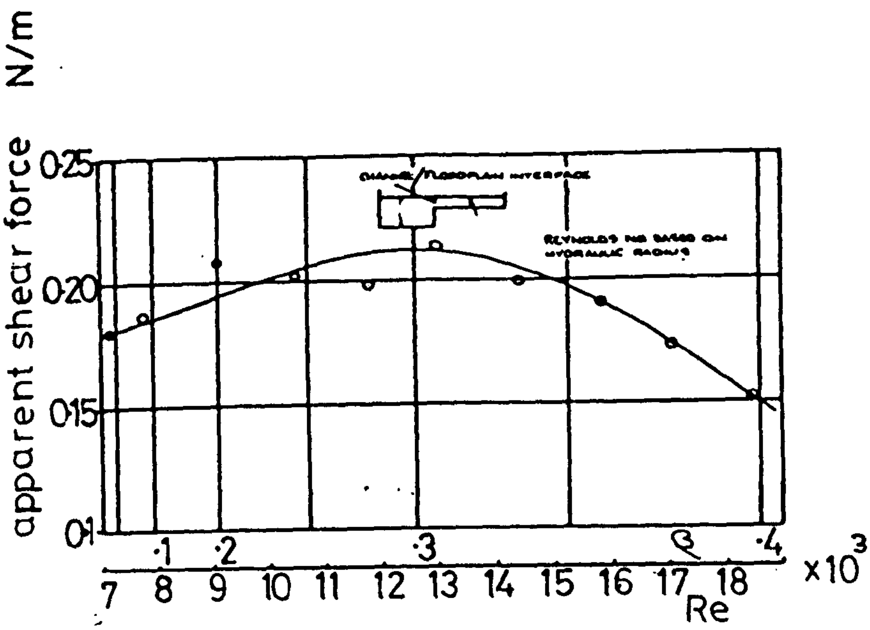


Boundary Shear Stresses in Compound Channel (Ghosh and Jena)

Figure 2.10

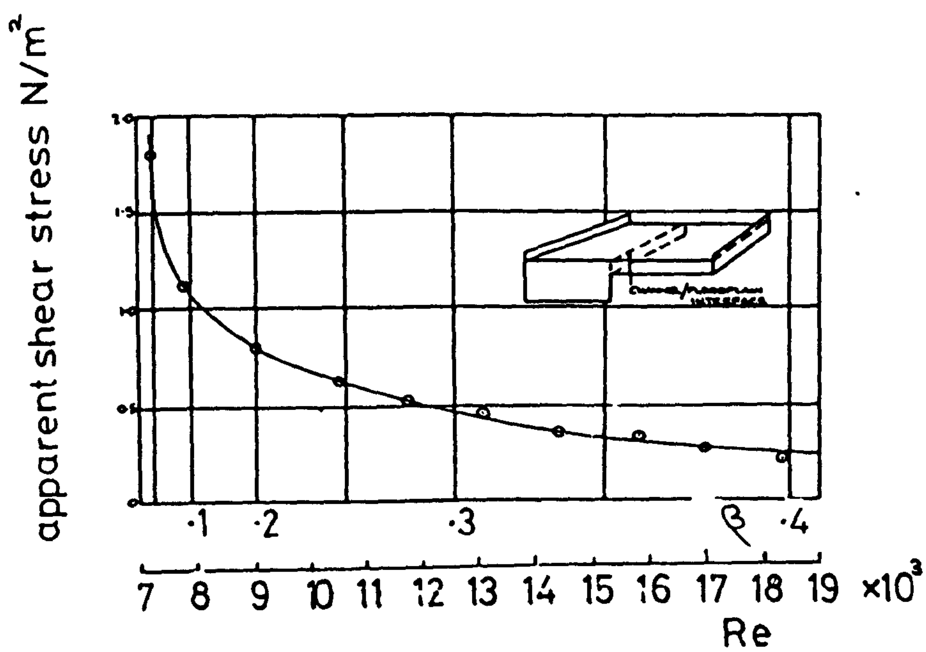
Myers (21), in 1978, investigated the "apparent shear force" between channel and floodplain, a term first coined by Cruff (7) investigating rectangular open channels in 1965. Myers drew attention to the high shear stresses along the channel/floodplain interface. He also tied up the apparent anomaly that existed between the highest turbulence levels recorded by Townsend at the lowest floodplain depths in contrast with the greatest velocity reductions recorded by Sellin and Zheleznyakov at a position noticeably above this. Having measured the boundary shear stresses for various depths of flow, he plotted "apparent shear stress" and "apparent shear force" for the vertical interface against Reynolds number, figures 2.11 and 2.12

These demonstrated clearly that the vorticity, driving the turbulent momentum transfer or shear stress was a maximum at the lowest depths. As the depth and area of interface increased, the shear stress decreased until a stage was reached where the product of area and shear stress was a maximum. This position corresponded to the maximum drag on the flow and hence resulted in the minimum velocity. Myer's experiments thus led people to realise that the "apparent shear stress" had to be taken into account across interfaces used in subdivision. It was now apparent why the "modified" methods proposed by Posey and Wright and Carstens were too inaccurate for very low overbank depths.



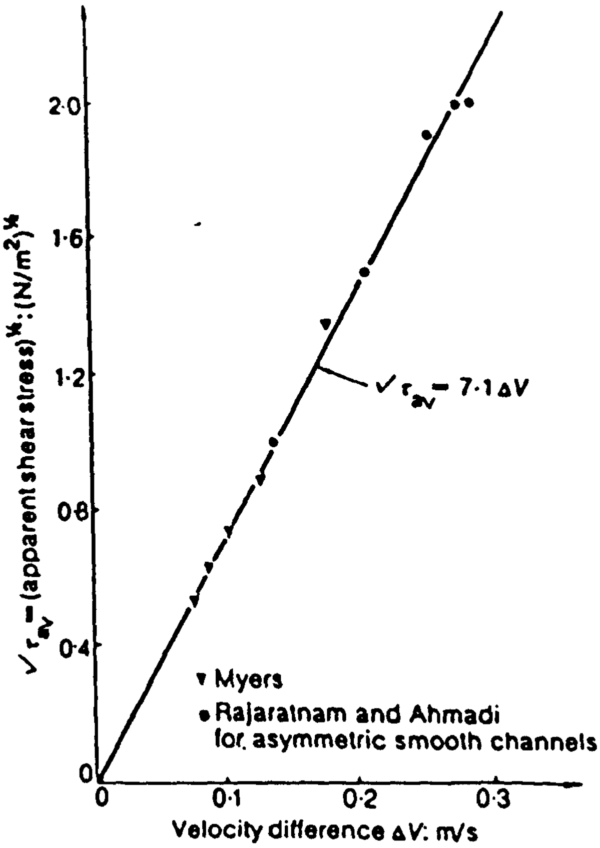
Apparent Shear Force against Re and β (Myers)

Figure 2.11

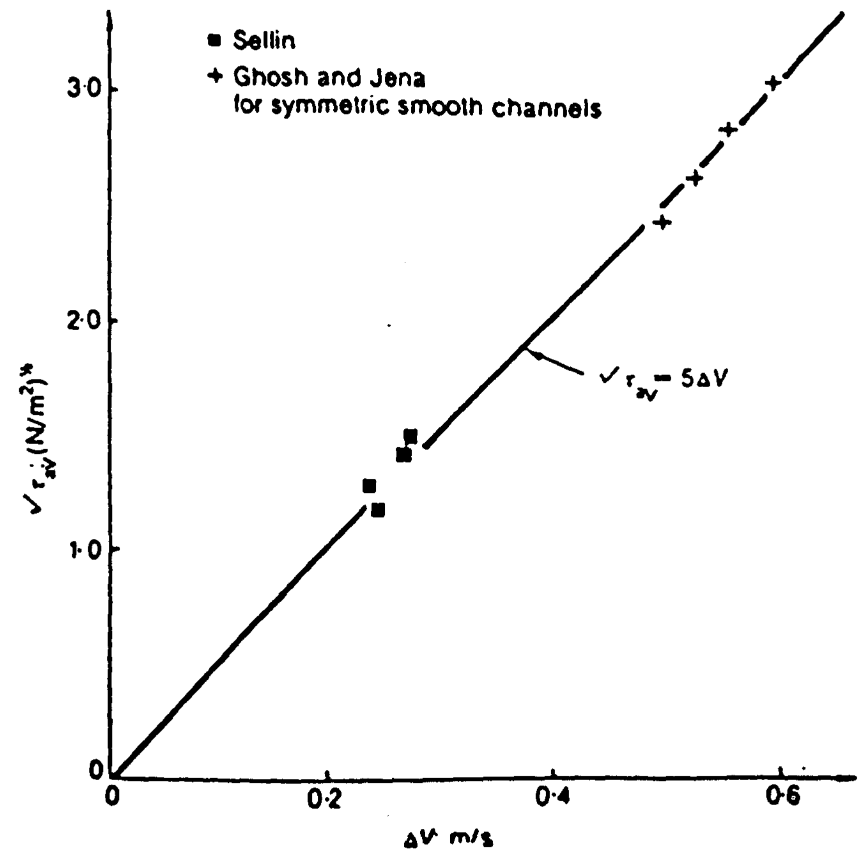


Apparent Shear Stress against Re and β (Myers)

Figure 2.12



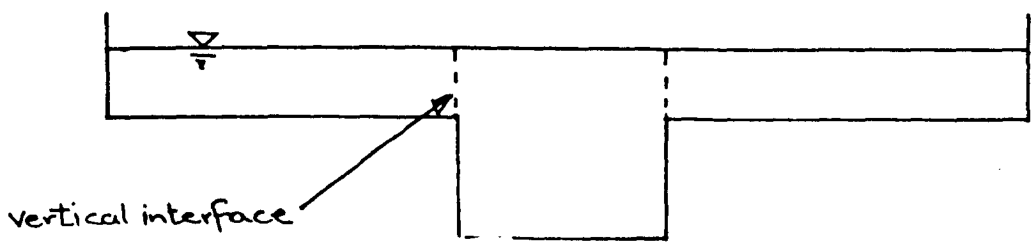
Apparent Shear Stress and Velocity Difference
for Asymmetric Channels (Ervine and Baird)
Figure 2.13



Apparent Shear Stress and Velocity Difference
for Symmetric Smooth Channels (Ervine and Baird)
Figure 2.14

2.4 Stage Discharge Relationships Using The Apparent Shear Force

Rajaratnam, in 1979 (31), and in 1981 (32) made further steps towards quantifying, τ_{av}, the average apparent shear stress across the vertical channel/floodplain interface. He concluded that it was a function of β, the dimensionless depth ratio.



For the range of geometries,

$\alpha = 2.43$

$\beta = 0.15$ to 0.25

$\gamma = 1.0$

$\delta = 3.65$

he produced the equation

$$\tau_{av}/\tau_{o\alpha} = 0.15((1-\beta)/\beta)^2 \qquad (5)$$

where $\tau_{o\alpha}$, is the undisturbed shear stress on the floodplain.

Ervine and Baird (10) also attempted to quantify τ_{av}, in a technical note published in 1982. They used various authors' data (35,12,32) to produce figures 2.13 and 2.14 below for asymmetric and symmetric channels respectively.

They demonstrated that for the range of geometries,

α = 1.75 to 4.0

β = 0.09 to 0.43

γ = 1.0

δ = 1.0 to 3.65

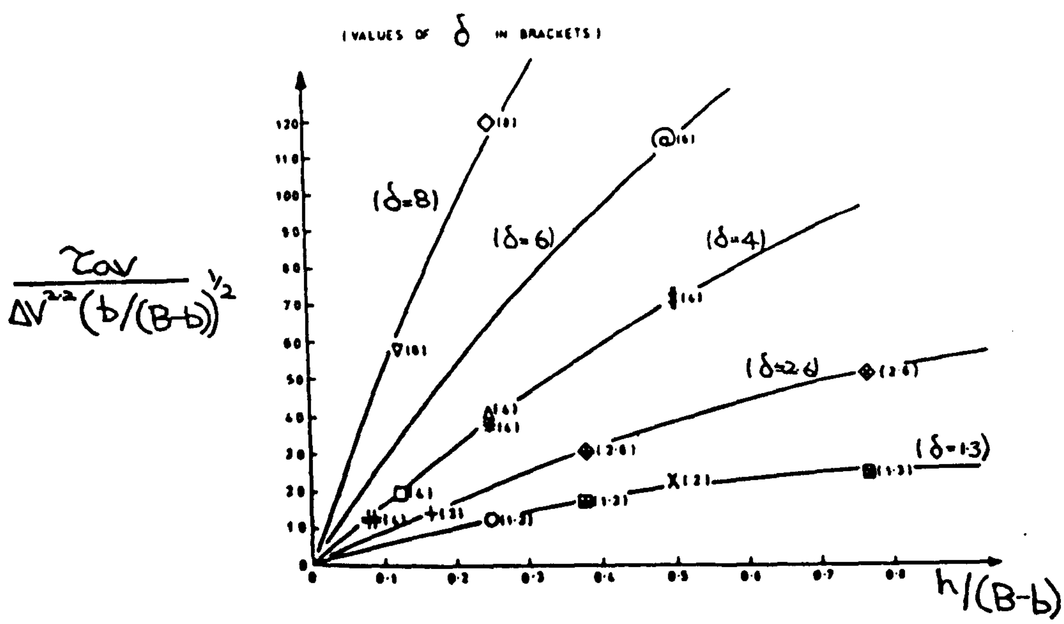
$$\tau_{av} = K(\Delta V)^2 \qquad (6)$$

where ΔV = Vc-Vfp, Vc,Vfp being the isolated mean channel and floodplain velocities respectively, calculated from Manning's equation.

In a subsequent publication (1), Baird and Ervine extended the idea of relating apparent interface shear stress to the relative mean velocity deficit between main channel and floodplain. They produced a relationship of the form

$$\tau_{av} = K\,\Delta V^{\left[2.2\,(b/(B-b))^{0.5}\right]} \times f_1\left(\delta\,,\ h/(B-b)\right) \qquad (7)$$

The range of results are plotted in figure 2.15 .



Variation of Apparent Shear Stress Parameter with Channel/Floodplain Geometry (Baird and Ervine)

Figure 2.15

In the same year, Wormleaton, Allen and Hadjipanos (43) provided much more detailed data on the apparent vertical shear stress, τ_{av}, using data obtained from Myers (23), Ghosh and Jena (12), and Elsawy and Crory (9), together with their own. They produced an equation of the form,

$$\tau_{av} = 13.84\, \Delta V^{.882} \cdot ((1-\beta)/\beta)^{-3.123} \cdot \alpha^{-0.727} \qquad (8)$$

within the range of geometries

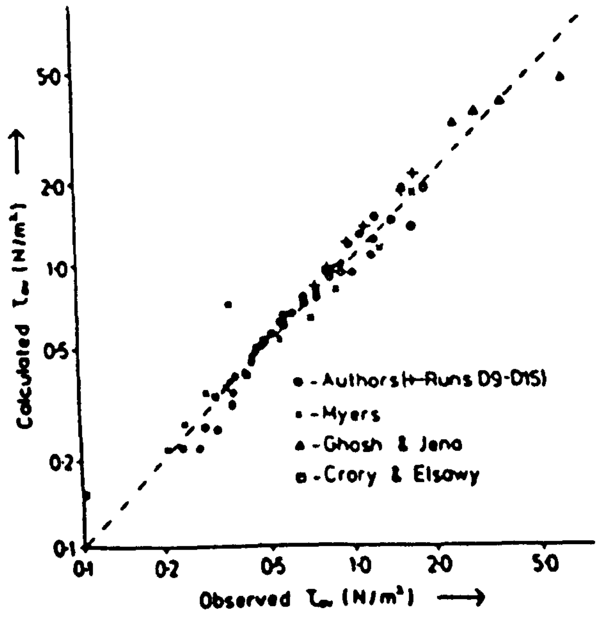
α = 1.75 to 4.18

β = 0.05 to 0.75

γ = 1.0 to 1.90

δ = 1.0 to 1.25

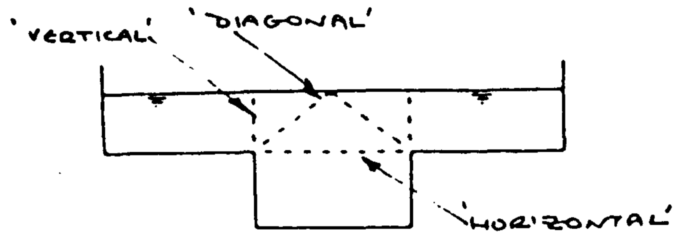
The correlation of this equation to observed data is shown in figure 2.16 .



Calculated vs Observed Apparent Shear Stress Values for Vertical Interface (Wormleaton et al)

Figure 2.16

The authors felt, however, that a simplified method was needed for calculating compound discharge by subdivision of the model section. They defined three sets of division planes within the flow, shown in figure 2.17 .

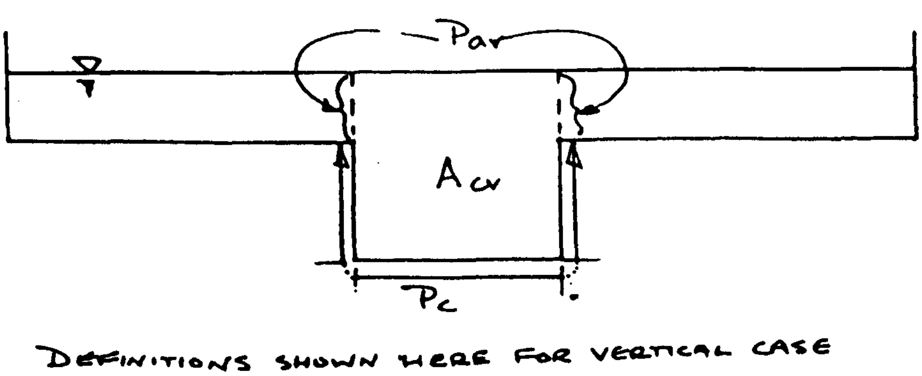


Division Lines Between Main Channel and Floodplain
(Wormleaton et al)
Figure 2.17

To each of these they attributed an apparent shear stress ratio, λ_i , defined as the ratio of the average shear stress across the imaginary boundary to the average channel shear stress, τ_{ci}, where

$$\tau_{ci} = (\omega A_{ci} S_o)/(P_c + P_{ai}) \qquad (9)$$

w-unit weight of water,Aci-channel cross-section area, S-friction slope, P-wetted perimeter and i denotes the generalised form of the equation - diagonal,d. horizontal,h, or vertical,v,. Figures 2.18, 2.19, 2.20 show λ_V, λ_D and λ_H plotted against the depth ratio.



DEFINITIONS SHOWN HERE FOR VERTICAL CASE

Figure 2. for the vertical case is very similar to Myers' plot of apparent vertical shear stress against Reynolds number, where the apparent shear is many times the average channnel shear. However, it is interesting to note the variation of λ_D and λ_H with depth ratio. These are much lower than λ_V . The authors then simplified the situation further by considering two options only, either including the division planes in the main channel wetted perimeter, $\lambda_i=1$, or excluding them, $\lambda_i=0$. the discharges were then found by applying Manning's formula for the main channel and floodplain subdivisions individually and then combining them to give the total flow.

In 1984, (42), the authors extended their ideas and introduced parameters ϕc and ϕf, Radojkovic (30), to characterise the momentum transfer process beteen the main channel and floodplain where

$$\phi_c = \tau_c / \omega R_c S_o \quad \text{———} \quad (10)$$

and

$$\phi_f = \tau_f / \omega R_f S_o \quad \text{———} \quad (11)$$

They produced

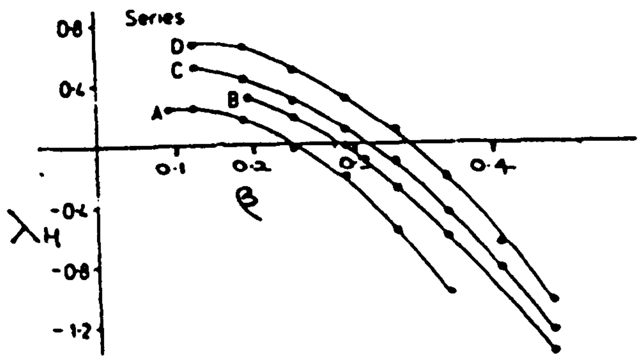
$$Q_{TOT} = Q_c' \cdot \phi_c^{\frac{1}{2}} + Q_f' \cdot \phi_f^{\frac{1}{2}} \quad \text{———} \quad (12)$$

where Q_c', Q_f' are the isolated main channel and floodplain discharges given by the Manning formula.

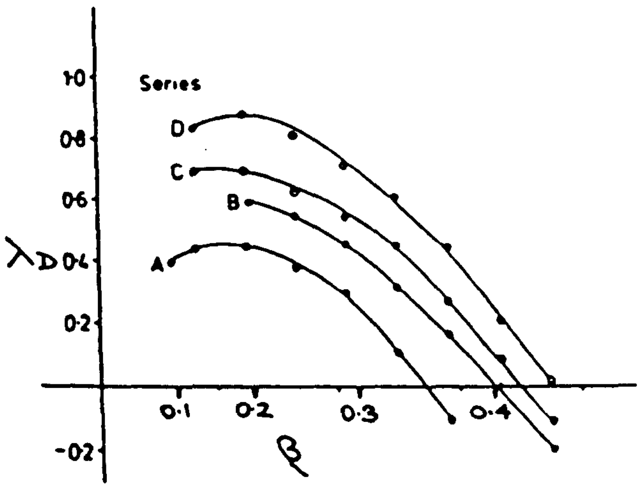
From a series of laboratory experiments, they evaluated ϕc and ϕf

for different interfaces and calculated Q_{TOT} using the equation above. The net transfer of momentum to the floodplain was clearly illustrated in their results for a vertical interface as they found that ϕcv was always less than unity and ϕfv always greater than unity.

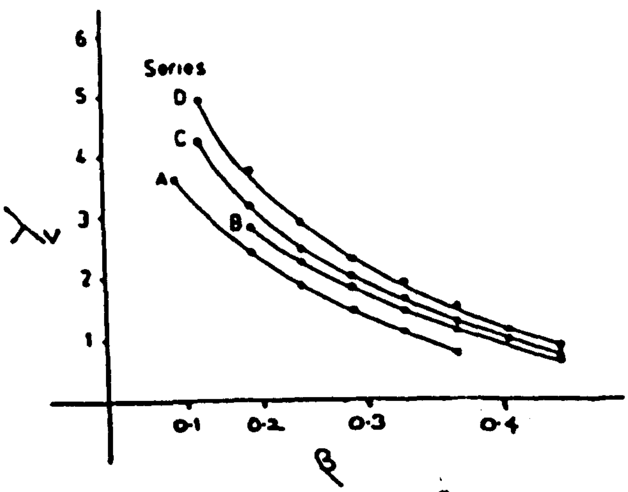
Figure 2.21 shows both the earlier method of including the vertical interface in the main channel wetted perimeter, calculating the disharge by the separate channel method, and the ϕ method.



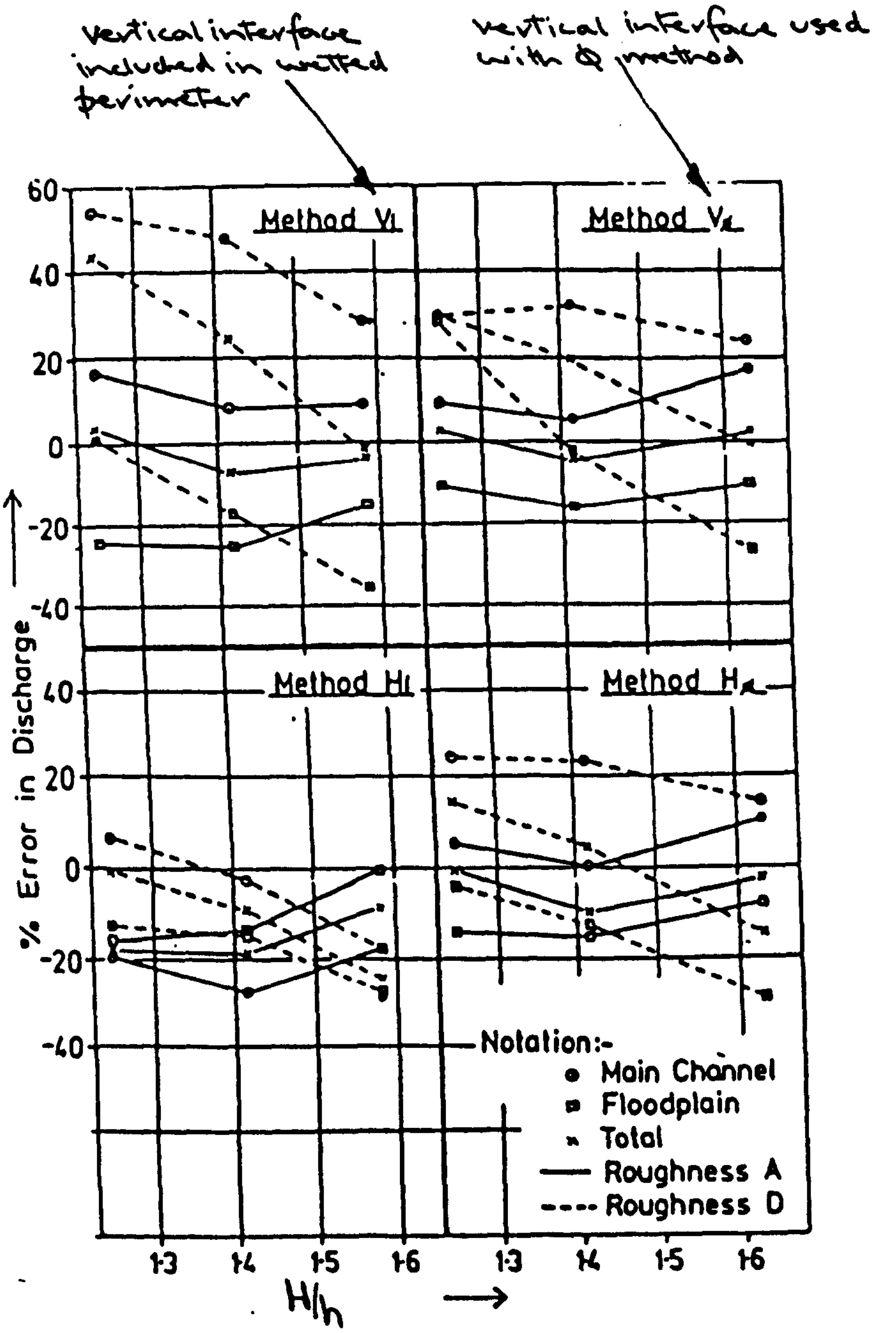
λh versus Depth Ratio for Horizontal Interface
(Wormleaton et al)
Figure 2.18



λd versus Depth Ratio for Diagonal Interface
Figure 2.19



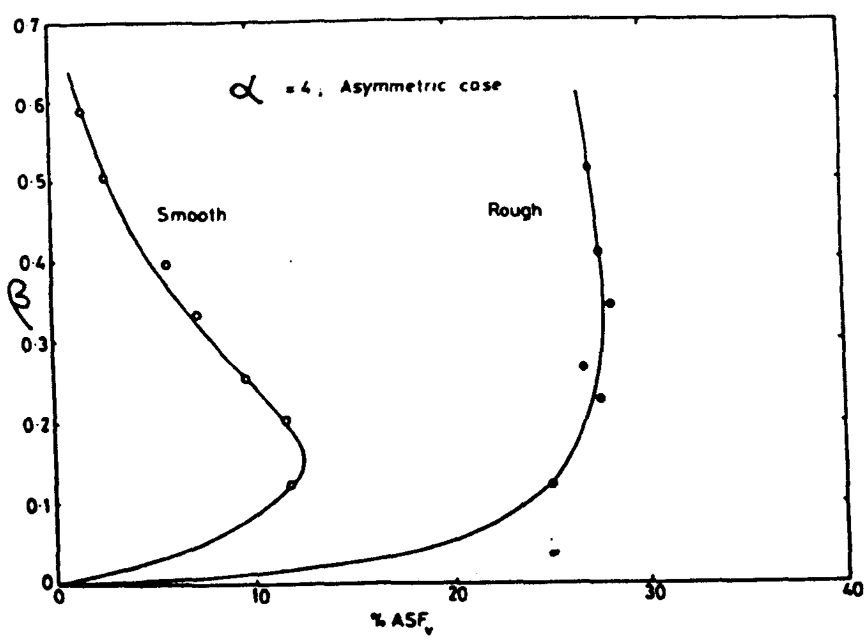
λv versus Depth Ratio for Vertical Interface
Figure 2.20



Variation in % Discharge Error with Depth Ratio
(Wormleaton et al)
Figure 2.21

In a subsequent discussion on (43), Buchanan (4) demonstrated that the single channel method with a single n value for the entire cross-section proved as effective as the authors more complex method. In response, the authors pointed out that the single channel method had no theoretical basis and theirs attempted to use the apparent shear stress across the boundary between channel and floodplain. It served to demonstrate, they felt, that the single channel method should feature as a yardstick by which future results and analysis might be measured.

Knight et al (16,17,18,19) have also carried out extensive work on this subject. They have followed a similar line to the other authors by the use of the "apparent shear force" on various interfaces. A graph has been reproduced below in figure 2.22 which plots %ASF, the percentage of apparent shear force across the floodplain /main channel interface to the total shear force on the main channel boundaries, against relative depth, β.



Variation of Apparent Shear Force on Vertical Interface (Knght et al.

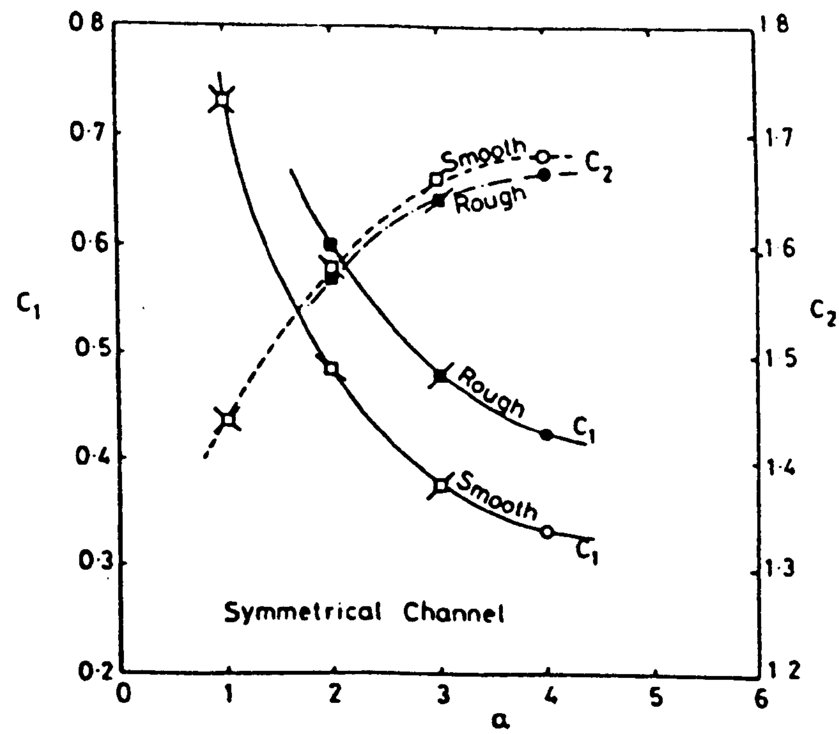
Figure 2.22

They proposed a relationship between depth and discharge of the form,

$$\mathrm{Log}_{10} H = C_1 \log_{10} Q + C_2 \qquad (13)$$

where values of C1,C2 are plotted against α for a smooth and rough case in figure 2.23

They also compared the accuracy of various design methods either including or excluding the interface between channel and floodplain in the calculation of hydraulic radius.

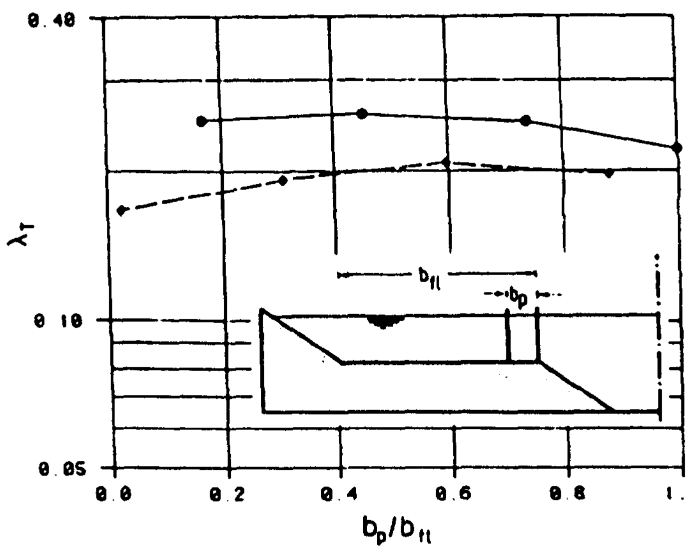


Variation of Constants C1 and C2 with α (Knight et al)

Figure 2.23

2.5 Vegetatively Roughened Floodplains in Prismatic Compound Channels

Pasche, Rouve, Evers and Indlekofer (12,15,25,26) presented over a period from 1980 to 1985 details of experiments on the more realistic case of heavily roughened floodplains. Pasche and Rouve (26) demonstrated that the width of the vegetation zone on the floodplain was of minor importance only to flow resistance in the main channel. This is demonstrated in figure 2.24, a plot of λ_T, a friction factor for the imaginary vertical wall between main channel and floodplain against width of wooded flood plain.
They also demonstrated that a flow region occurs on the vegetated floodplain which is not influenced by the main channel flow.



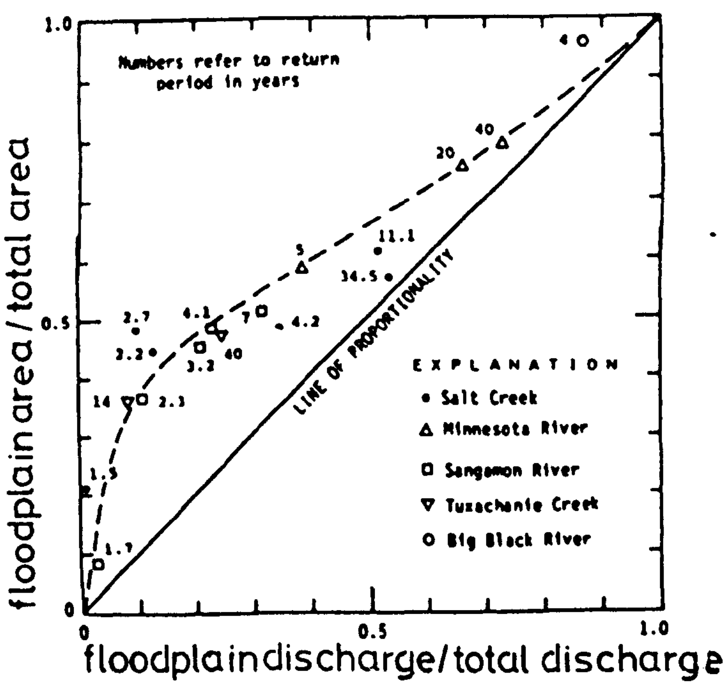
Friction Factor, λ_T, for vertical interface vs dimensionless width of wooded floodplain (Pasche and Rouve)

Figure 2.24

Nalluri and Judy (24) carried out experiments on prismatic compound channels with heavily roughend floodplains, with n (floodplain) up to .041 and n(main channel) between .02 and .03 .

2.6 Field Data

Little field data have been collected or analysed compared with the wealth of laboratory data available. Tingsanchali and Ackermann (36) and Bhowmik and Demissie (3) both showed that floodplains must be considered as conveyance channels as well as storage channels. Figure 2.25 shows how with increasing size of flood the floodplain becomes less of a storage channel and more a conveyance channel.



Plot of Floodplain/Main Channel Area to Discharge Ratio

(Bhowmik and Demissie)

Figure 2.25

2.7 Mathematical Models

The topic is not covered here but has been mentioned for completeness. Two references on mathematical modelling are included, (41,20), the latter, Krishnappan and Lau have compared their Turbulent Model of floodplain flows to data produced by Knight et al. Good agreement has been obtained.

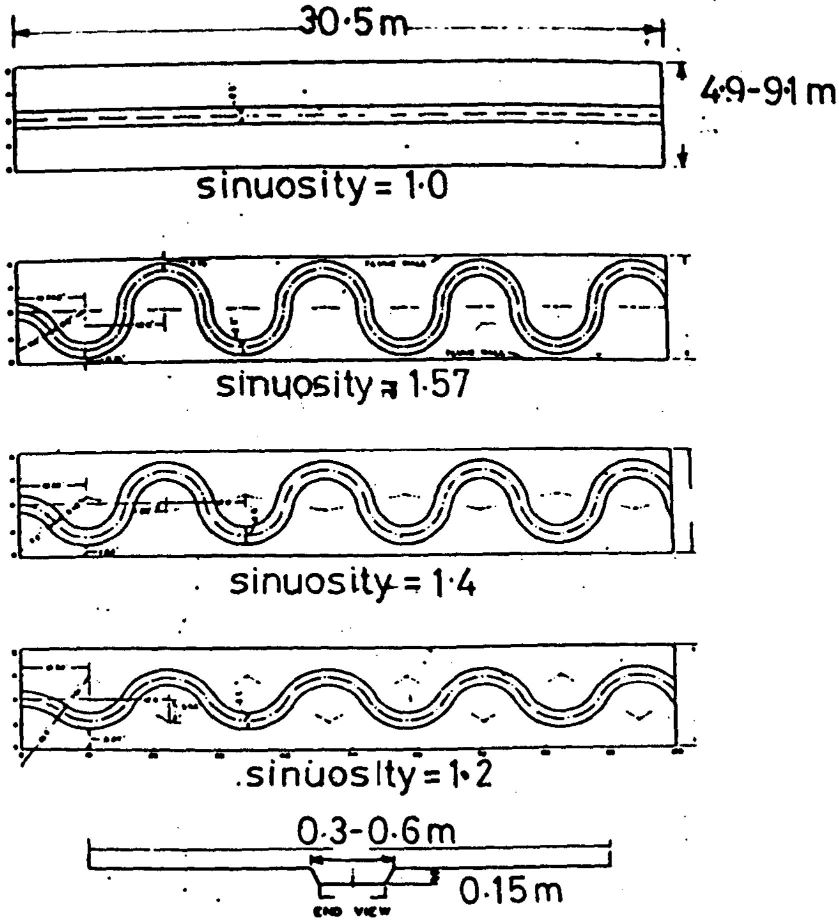
2.8 Meandering Compound Channels

As mentioned earlier, very little work has been done on this type of compound channel. The earliest report directly related to the above topic is a publication by the Waterways Experiment Station, Vicksburg, Mississippi, in 1956. (40). Many useful data were presented for a range of
β =0.2,0.4,0.6, and γ =1.0,2.1,2.9. although very little analysis was carried out on the data.

The conclusion one can draw from the report is that the meandering case of compound flow is far more complex and depends on more parameters than the simpler case considered in the first two chapters. Shown below are a number of graphs selected from the report to highlight the effect that a meander has on the discharge characteristics of a river. In this report, the strength of the meander has been termed the "sinuosity". Figure 2.26 is a schematic plan of the model with details of the different meander configurations. Figures 2.27 and 2.28 are plots of depth discharge relationships for various values of "sinuosity" and roughness ratio, γ.

Toebes and Sooky (26), in 1967, published a report titled "Hydraulics of Meandering Rivers with Floodplains ". They attempted to analyse their results in more depth than the previous report and concluded that the energy losses in the model depended both on Reynolds number and the Froude number.

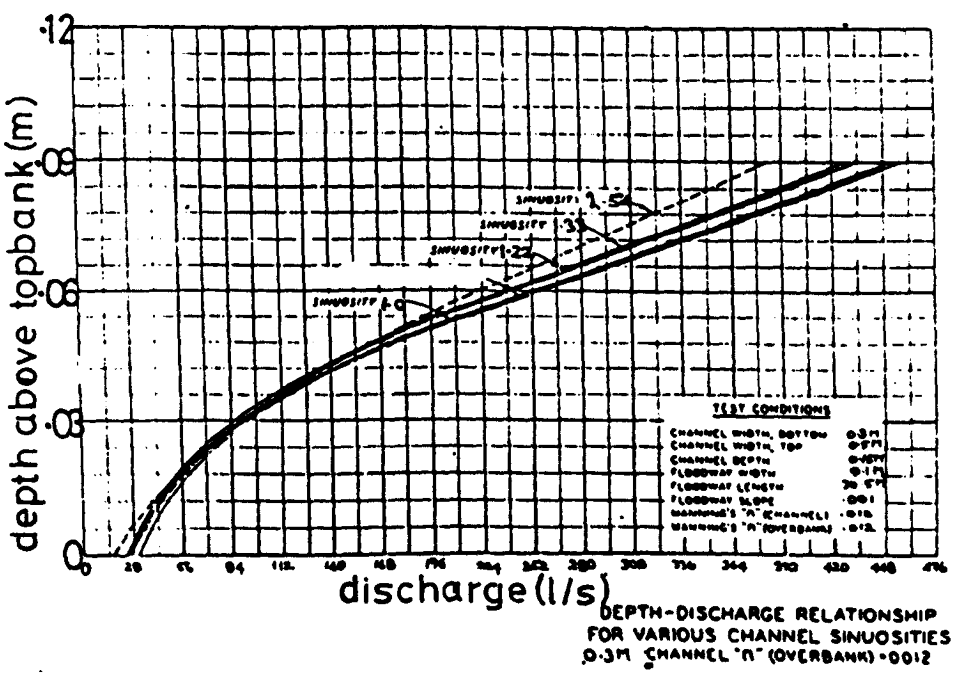
They proposed that a method for calculating discharge could be based on the horizontal division of channel and floodplain flow at the junction of the two. They further suggested that an equivalent



Plan of Model With Different Meander Configurations

(Waterways Experiment Station, Vicksburg)

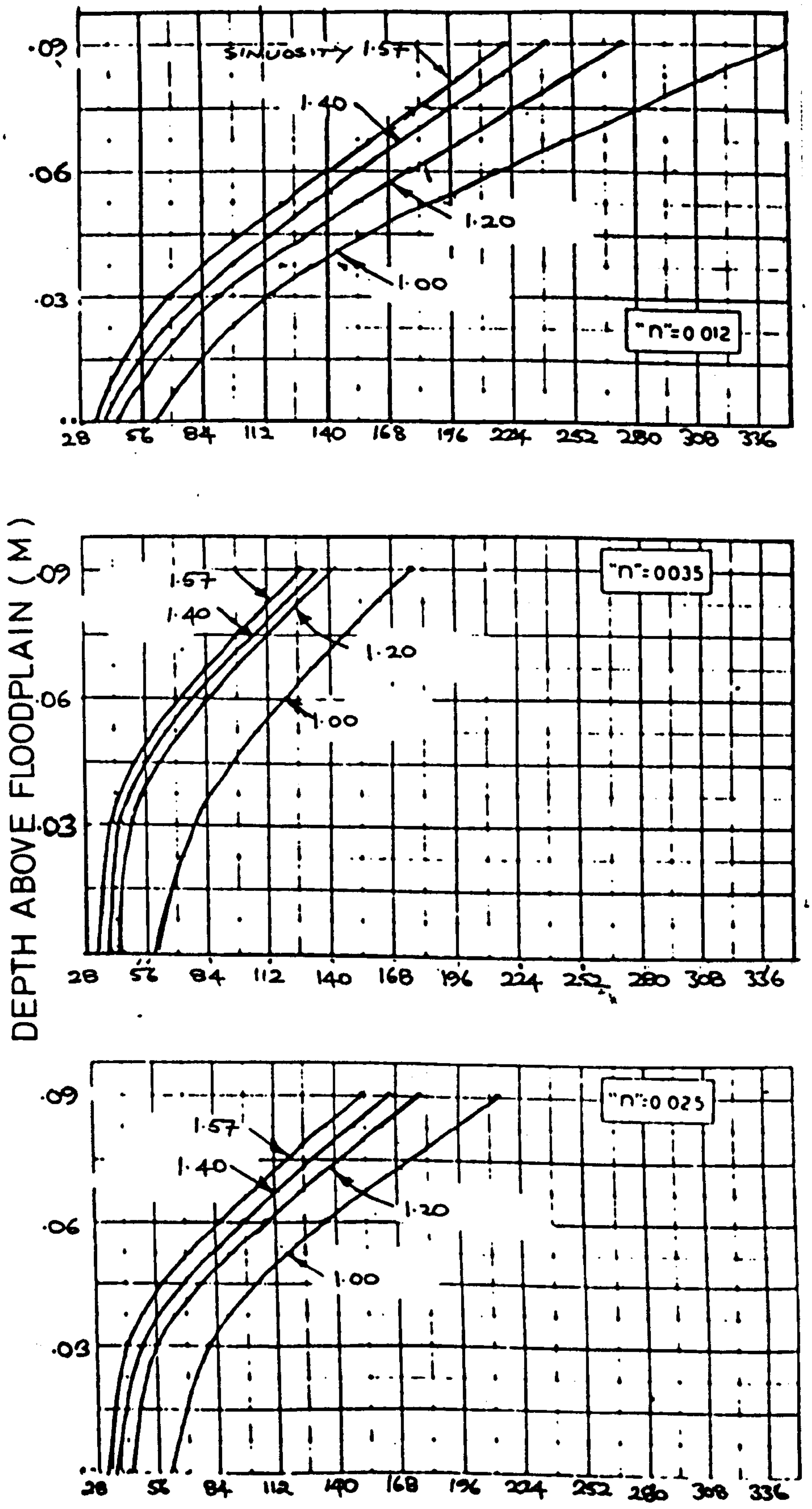
Figure 2.26



Depth Discharge Relationships for Various Sinuosities and Roughness

(Waterways Experiment Station, Vicksburg)

Figure 2.27



Depth Discharge Relationships for Various Sinuosities and Roughness
(Waterways Experiment Station, Vicksburg)

Figure 2.28

wetted perimeter,T, could be used across this interface to correspond to the apparent shear forces across it. Figure 2.29 shows the mathematical solution to the equation below,

$$Q_5 = Q_1/(1+(T-b)/P_1)^{\frac{1}{2}} + Q_3/(1+T/P_3)^{\frac{1}{2}} \quad (14)$$

where the subscripts refer to the geometries detailed in figure 2.30

The authors carried out detailed velocity traverses of various sections. Some of these have been included in figure 2.31 .

Rajaratnam (27), has produced a report recently, titled "Meandering Channels with Floodplains". In this he has considered two distinct configurations

$\xi = 0.37$

$\xi = 0.45$

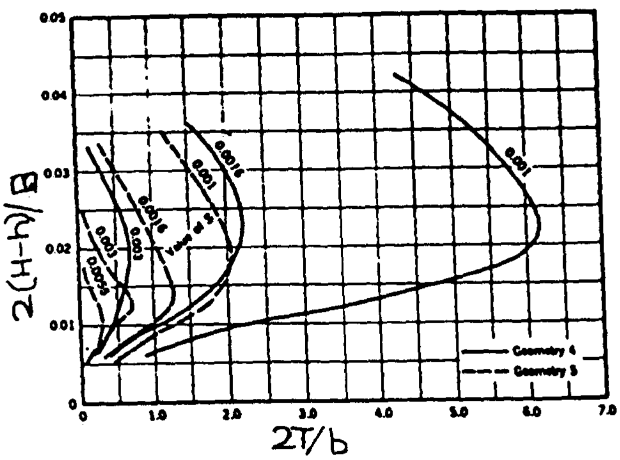
He concluded

1) that the main channel was not exclusively the location of the highest velocities in the section.

2) The maximum velocity filament (also observed by Toebes and Sooky) tended to roughly follow the inner sidewalls of the main channel.

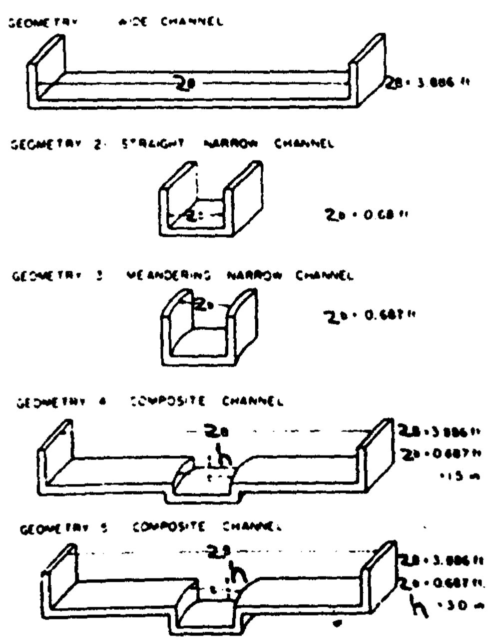
3) In the floodplain, the velocity varied continuously with distance above the bed whereas the main channel velocity remained almost constant with distance above the floodplain bed level. See Figure 2.32

Figure 2.33 gives the schematic plan layout of the model with details of the locations of the cross-sections in the curved



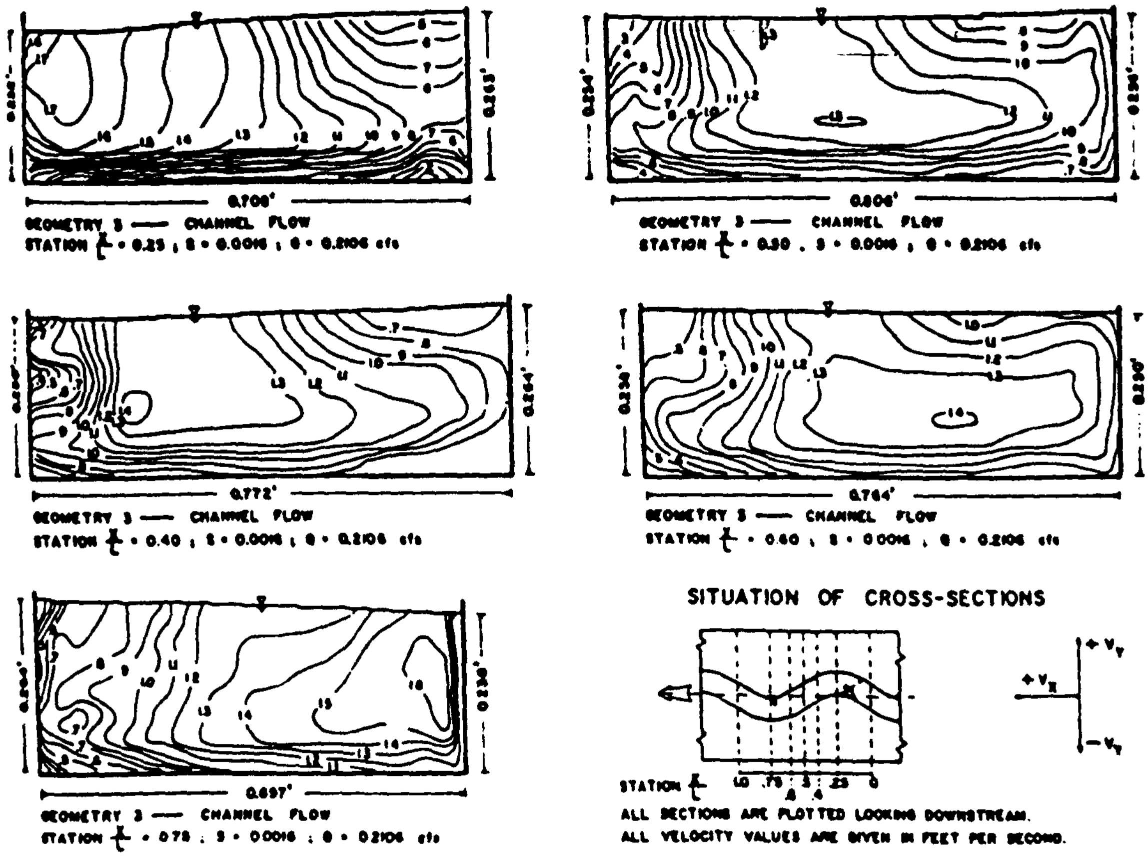
(Toebes and Sooky)

Figure 2.29

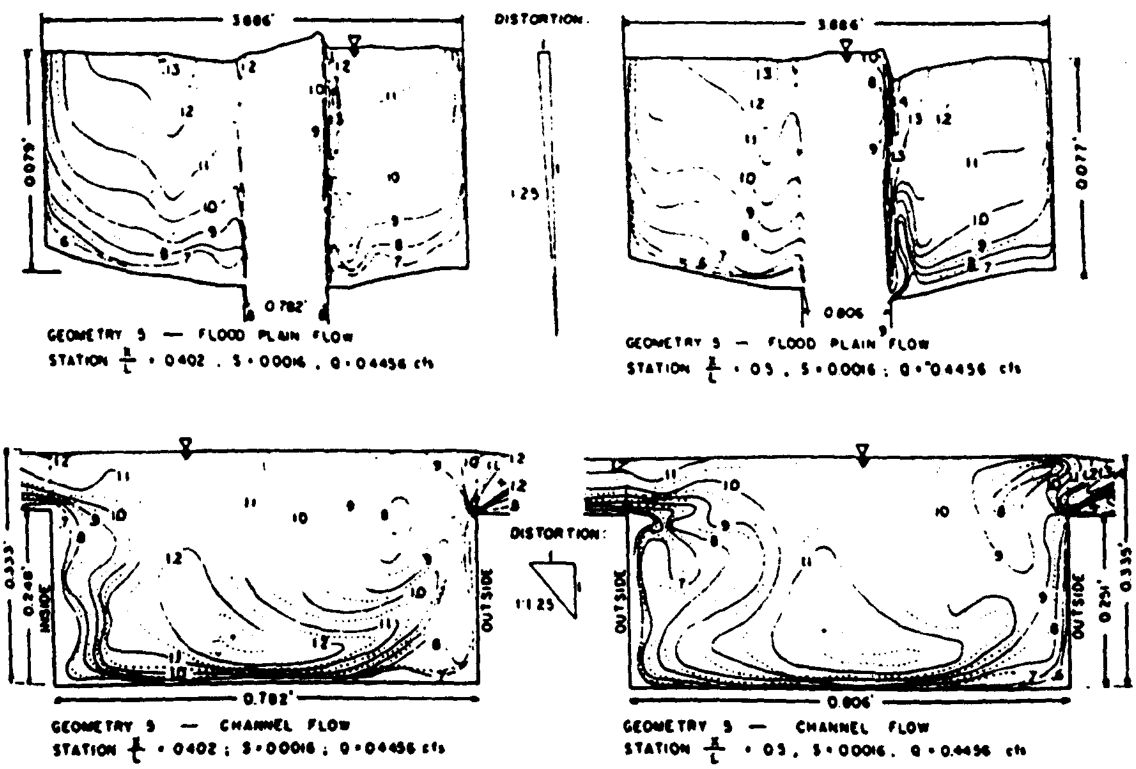


Model Geometries (Toebes and Sooky)

Figure 2.30



—VELOCITY CONTOURS, V_x

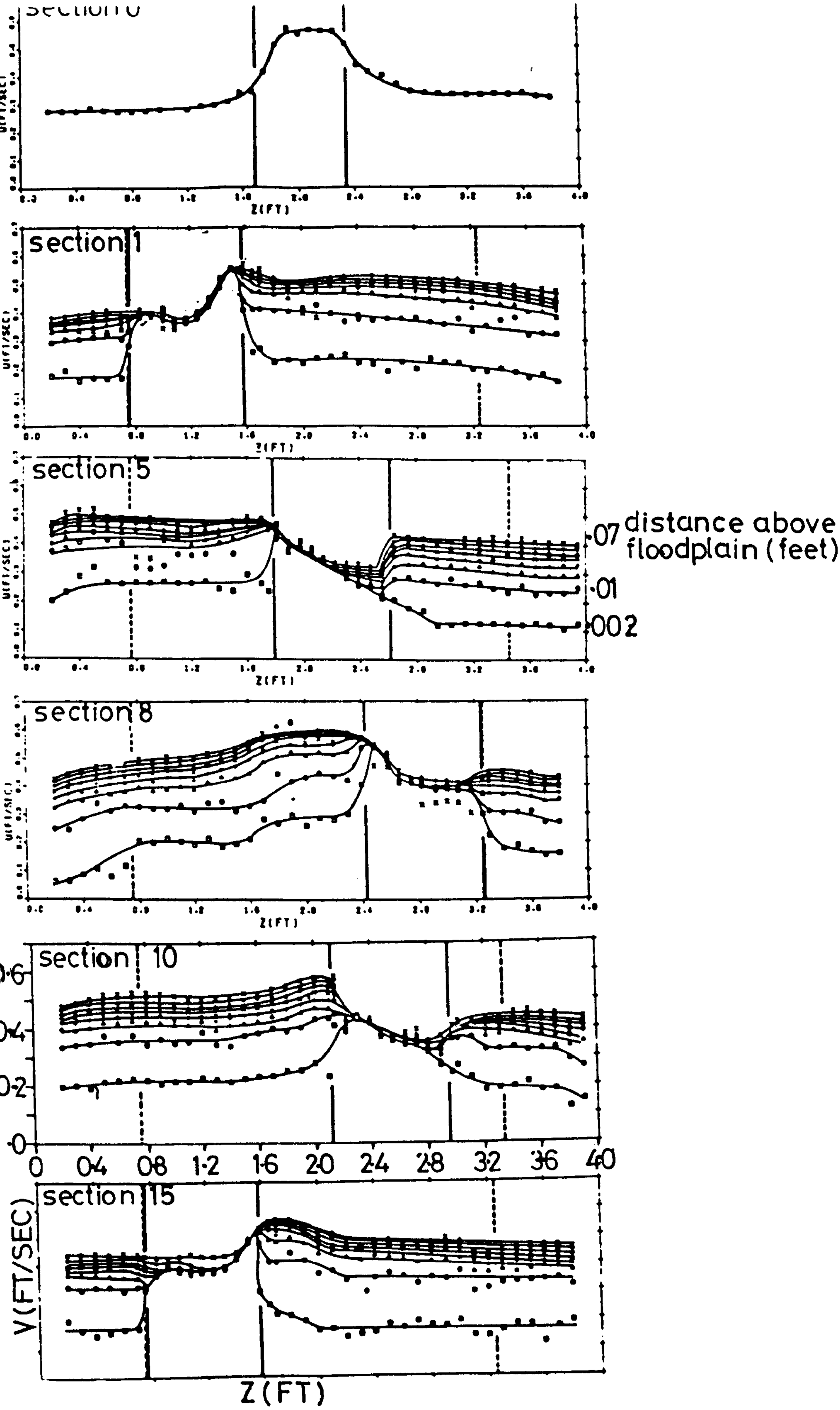


—VELOCITY CONTOURS, V_x

Isovels in Main Channel and Floodplain Cross-Sections

(Toebes and Sooky)

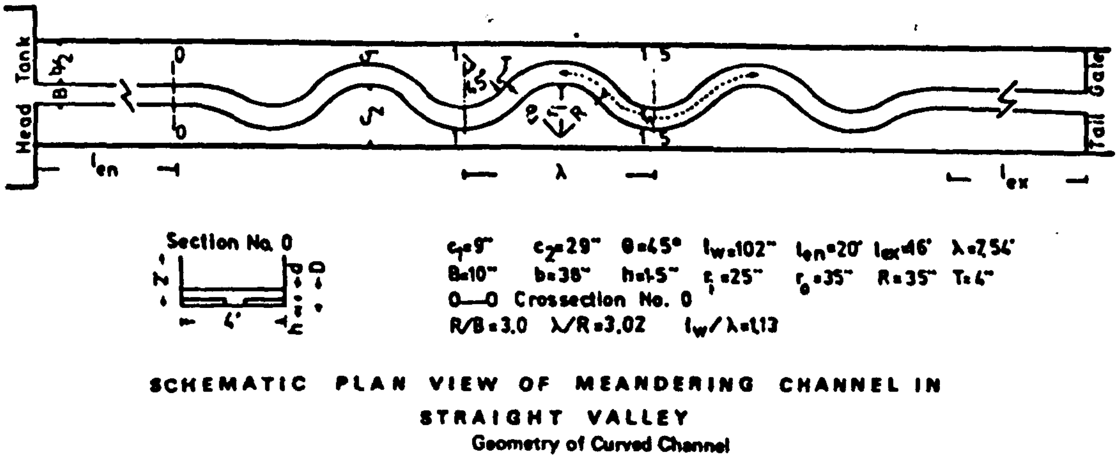
Figure 2.31

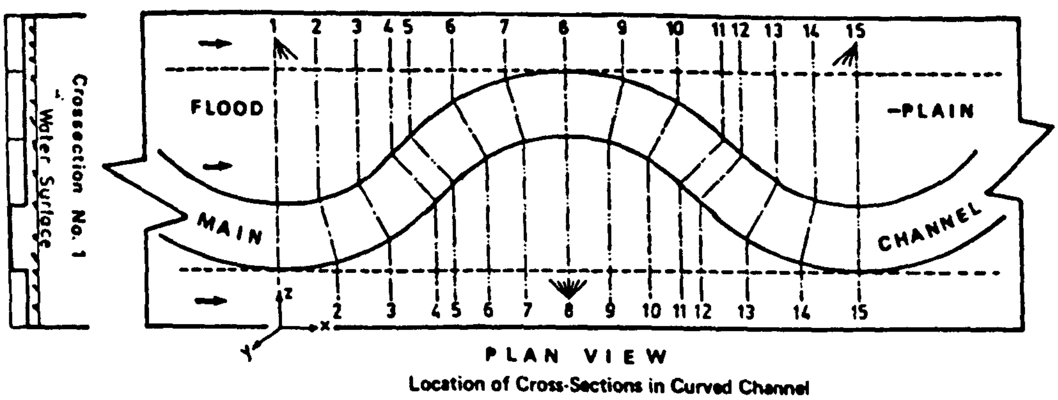


Depth Averaged Velocities Across Section of Model

(Rajaratnam and Ahmadi)

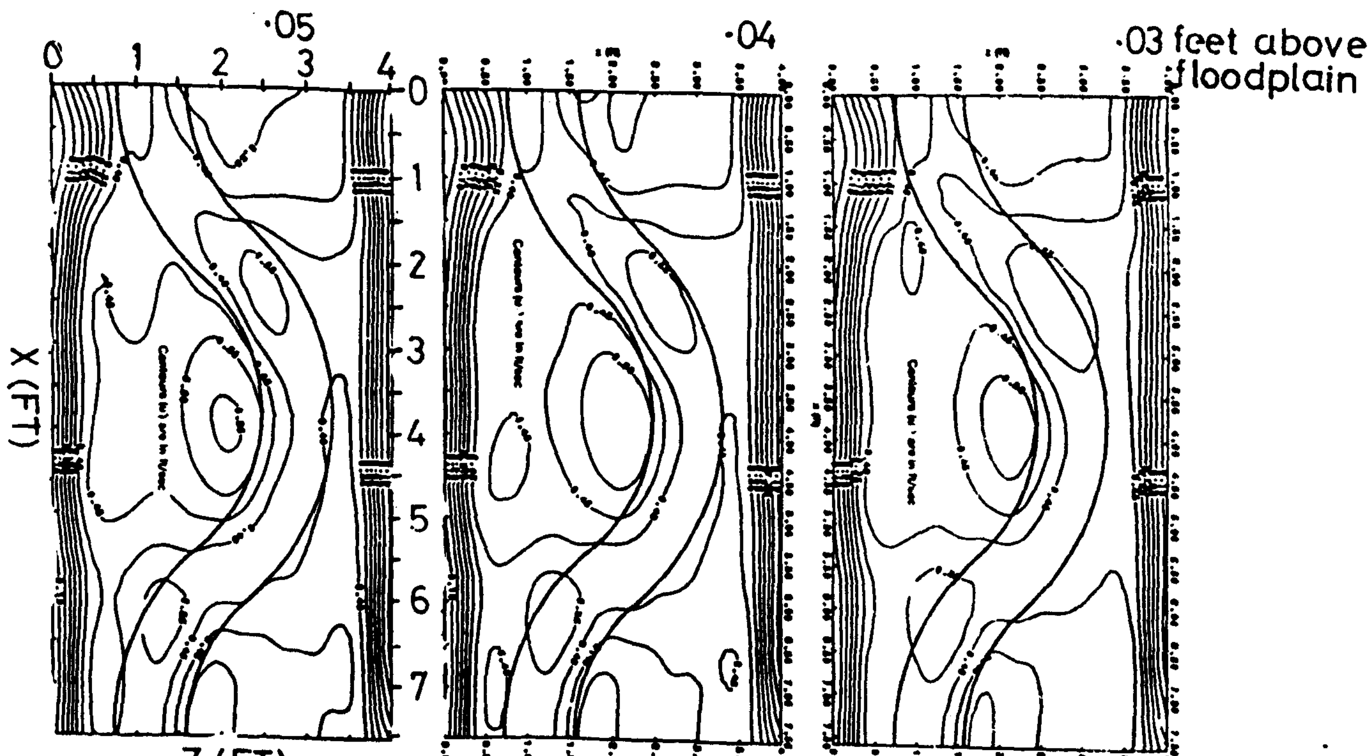
Figure 2.32





Model Layout (Rajaratnam and Ahmadi)

Figure 2.33



Velocity Isovels through Horizontal Sections of Model

(Rajaratnam and Ahmadi)

Figure 2.34

channel. Figure 2.34 is an example of the isovels recorded at different levels above the floodplain. It only remains to be said that a definable flow pattern is clear from the various graphs presented in this chapter and a great deal more research needs to be done in this field before we will be able to confidently predict generalised discharge formulae for the meandering channel configuration within a floodplain.

CHAPTER 3

EXPERIMENTAL APPARATUS

This chapter describes the flume and discharge facility designed and constructed for the experimental laboratory programme. New techniques for data measurement and data collection, developed for the project, are described.

3.1 Flume

3.1.1 Design and Construction of Flume

The laboratory model was constructed and operated in a purpose built steel flume. The design criteria for this flume were as follows:

1. High Stiffness under water load
2. Variable tilt
3. Dimensions approximately 300mm deep by 1200mm wide and as long as practicably possible.

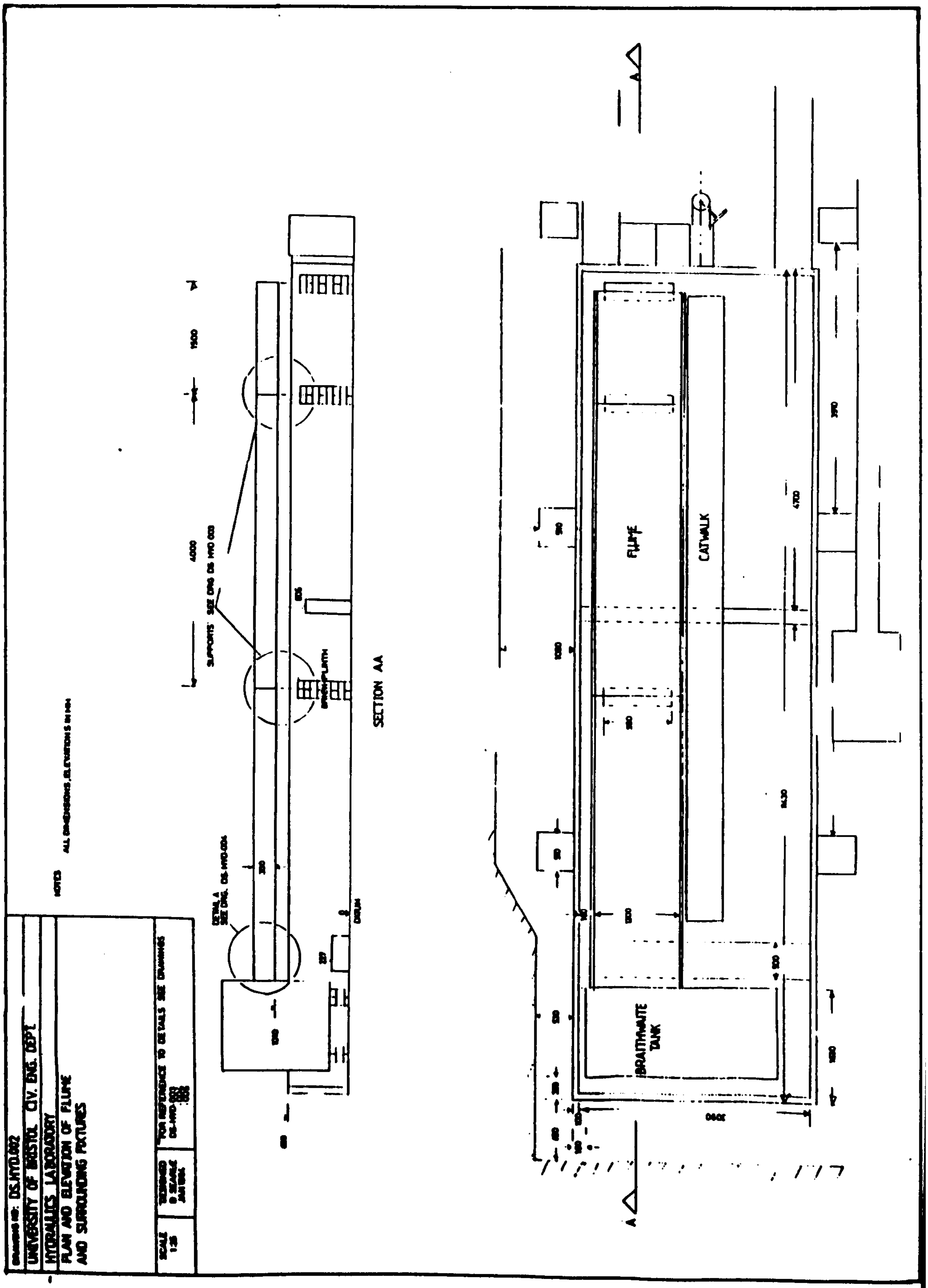
Steel was selected as the construction material because of its low cost and high stiffness compared with wood and perspex or glass and steel combinations. The shell of the flume was formed from mild steel sheet pressed to the shape of a shallow U with horizontal flanges at the top. These flanges provided added stiffness and were also intended to act as a base for mounting guide rails on.

The pressed metal sheet was stiffened with 50mm x 50mm x 4mm steel angle and hollow rectangular sections which were welded on to it at the correct spacings. The flume was made up from three lengths, two of 4 metres and one of 1.5 metres. They were bolted together and supported at the joints and at each end of the flume. A computer programme was used to investigate the elastic buckling limits of the steel for a variety of stiffener spacings, steel thickness and overall dimensions. The whole assembly was hinged at the upstream end and simply supported at the two joints and the downstream end. The bed slope of the flume could be altered by raising or lowering the supports with simple screw jacks. Each jacking point comprised of a pair of 25mm diameter, fine pitch, steel bolts welded to a horizontal box member resting on a brick plinth.A top box member,with locating holes drilled into it for the bolts to pass through, rested on two nuts threaded on to the bolts. In turn, this upper member supported the flume and thus, the rotation of the nuts altered its level. To adjust the bed slope, the six jacks, two at each jacking section, were adjusted in proportion to their distance from the upstream hinge.

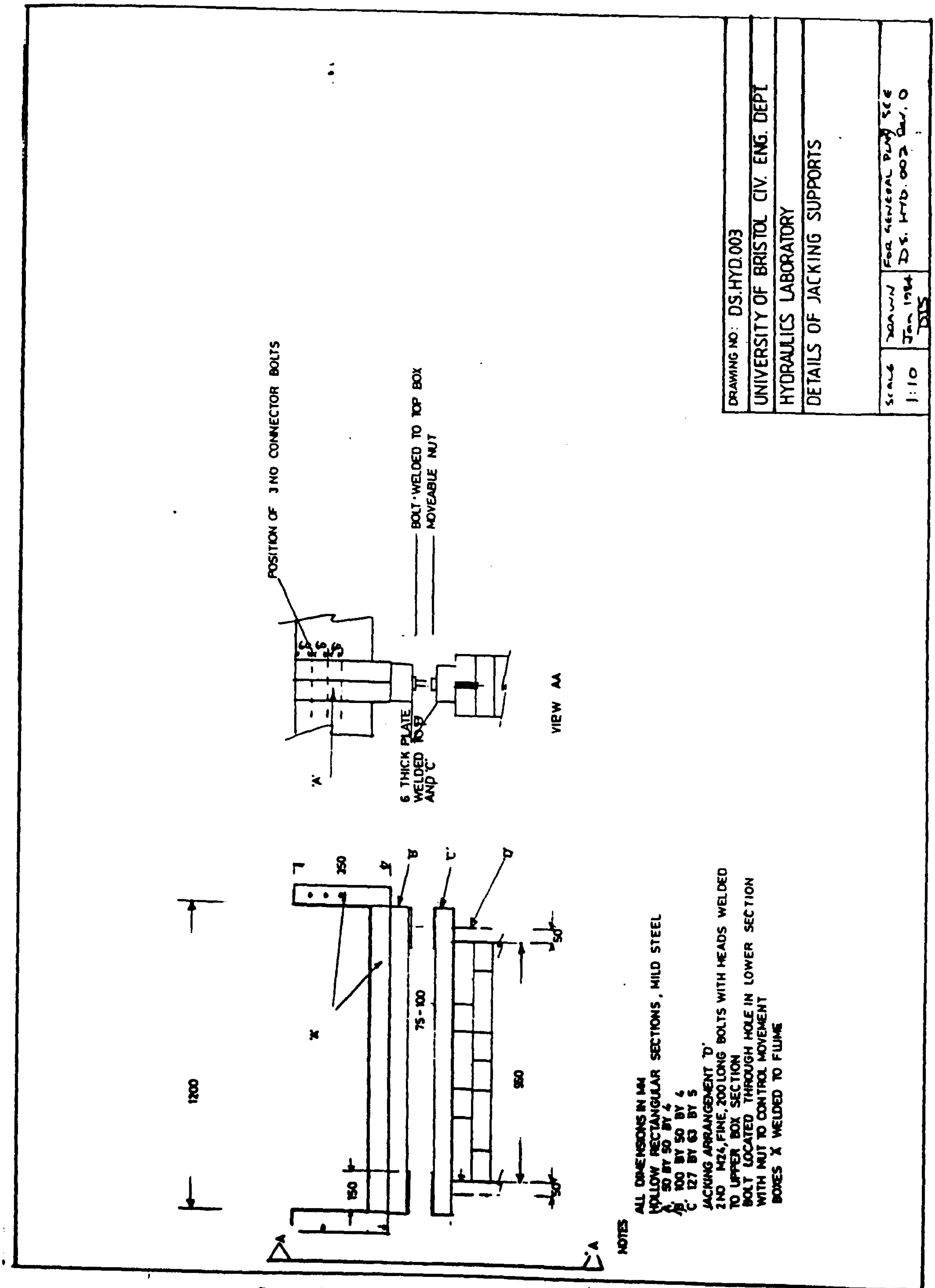
The bed level of the flume was checked at each jack point and the level adjusted again until the correct slope had been obtained for the entire length of the flume and the bed horizontal across the flume width. Levelling was carried out using an automatic Kern level set up on a tripod about 5 metres from the flume. A 500mm steel precision rule was used as the measuring staff.

The upstream end of the flume was hinged to a modified braithwaite tank which acted as an inlet stilling basin into which the supply water flowed. The tank was 2 metres wide, 1 metre deep and approximately 1 metre high with one panel cut down to half its height to accommodate the flume inlet. Three baffles dividing the tank, smoothed out the flow discharging into the tank from the constant head supply. A flexible seal between the flume and tank allowed the flume to tilt about its hinges.

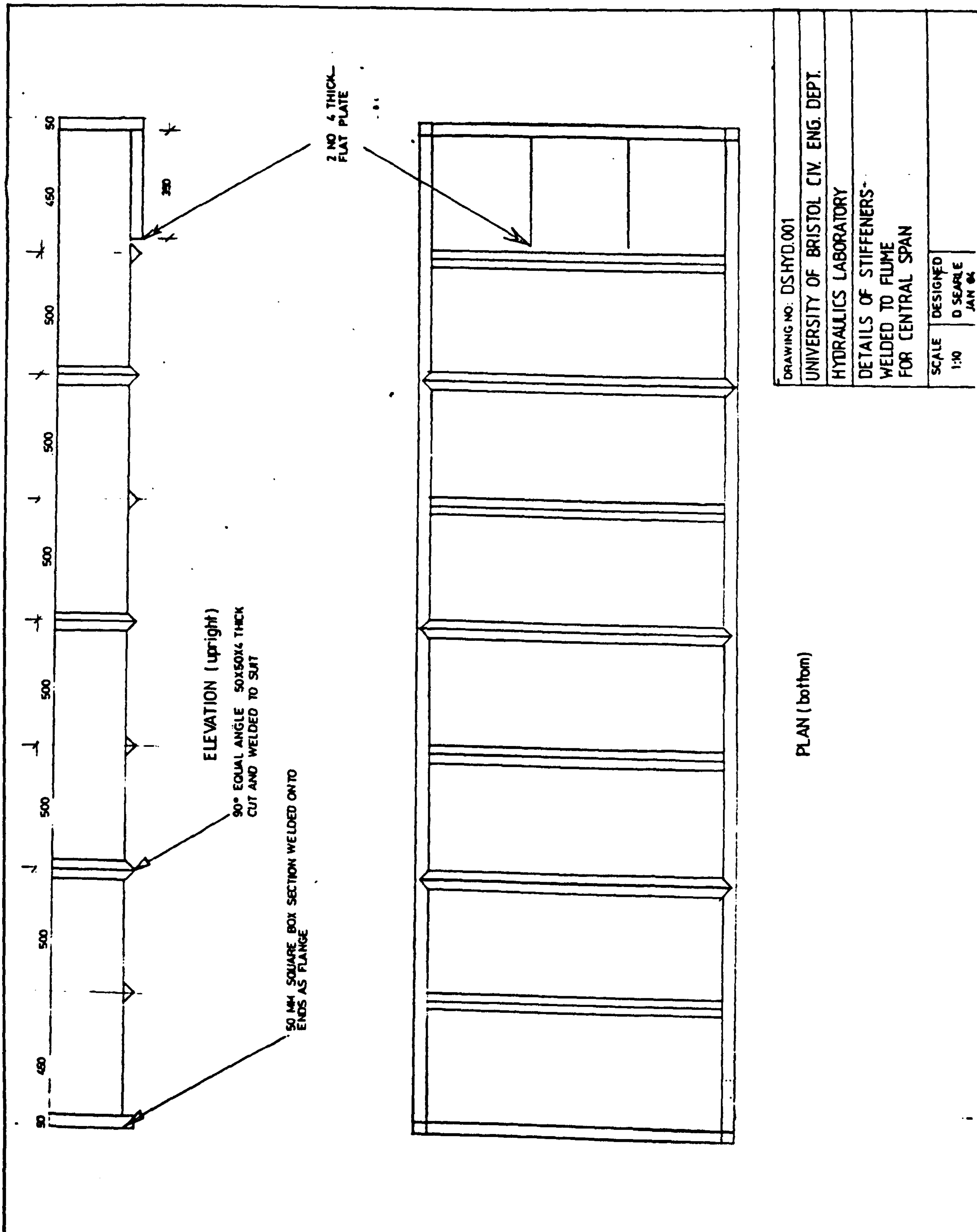
Figures 3.1, 3.2 and 3.3 show the overall flume layout, jacking points and stiffener details.



Overall Flume Layout
Figure 3.1



Details of Jacking Supports
Figure 3.2



Stiffener Details for Central Span of Flume
Figure 3.3

3.1.2 Tail Gate Mechanism

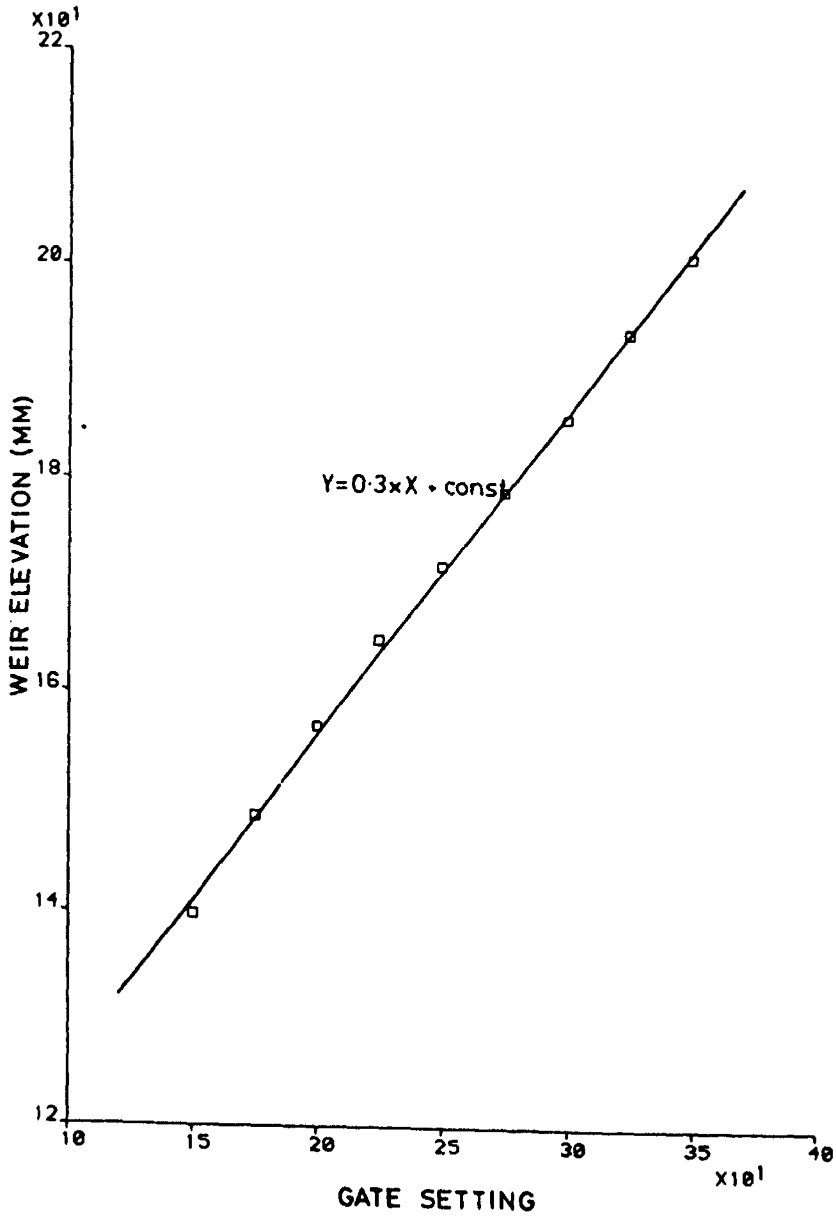
The flume discharged over a broad crested weir gate. The cable and drum winding mechanism of the gate was motorised with the operating switch connected to a travelling overhead cable which could be extended the length of the flume. Thus the operator could be working anywhere along the the flume and still have immediate control of the weir gate.It was possible to control the downstream water level to within 1mm with reference to a marked disc on the circumference of the winding drum and thus an absolute gate level could be repeated. Furthermore, the slow winding rate of the drum resulted in minimal wave disturbance travelling up the flume during gate level changes. A 10kg lead weight, attached via a steel cable and running over a pulley to the downstream side of the weir gate, ensured that the gate did not 'stick' whilst being lowered.

Figure 3.4 shows the relationship between tail gate level and gate setting.

3.1.3 Water Supply

To provide controlled discharge with discrete variations, a constant head tank was installed above the stilling basin, discharging water through a series of orifices. A bank of 9 orifices approximately 30mm in diameter, 6 orifices about 10mm in diameter and one orifice 7mm in diameter, were drilled into the underside of the tank, giving a flow range from 0.1 litre/second to 15 litres/second in steps of about 1.5,0.2 and 0.1 litres/second for each size of orifice.

The orifices were calibrated volumetrically in the cumulative



Tail Gate Setting vs Weir Elevation
Figure 3.4

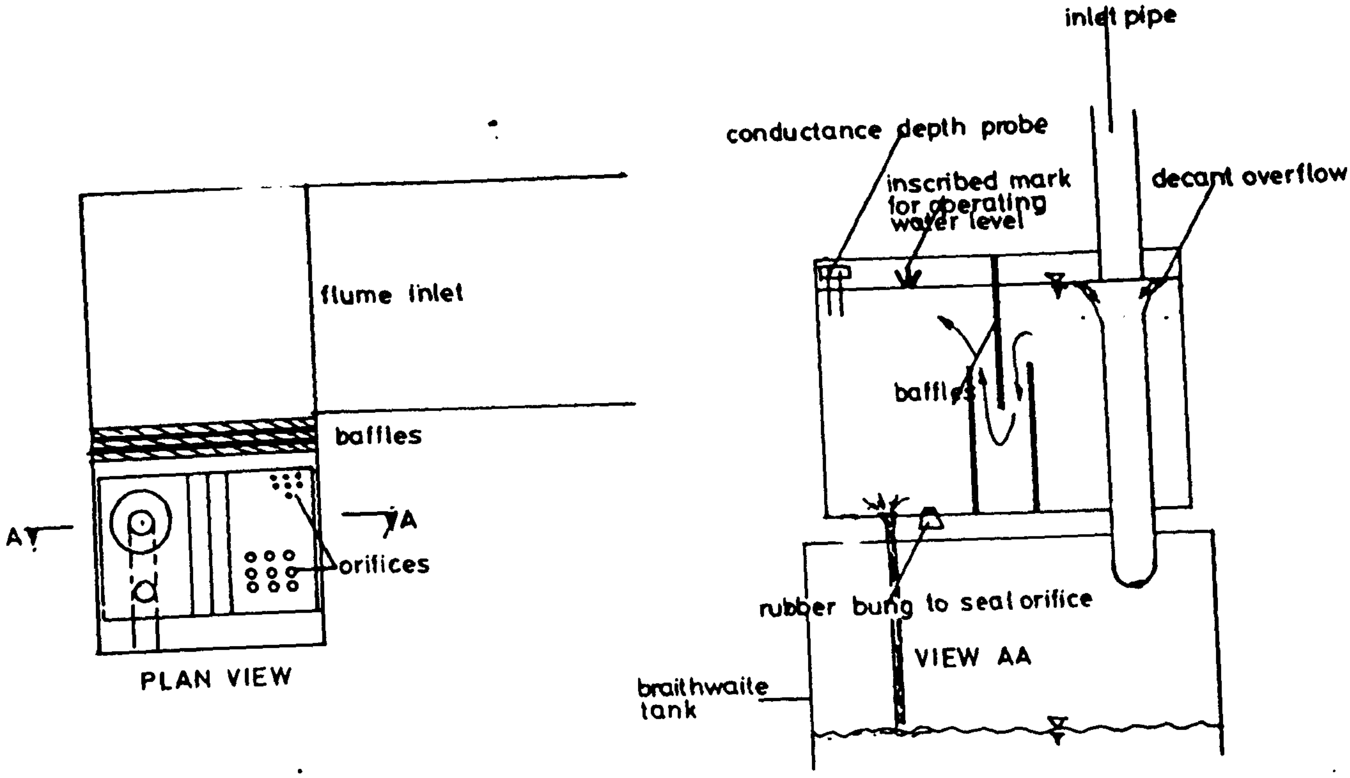
sequence in which they would be used. as some interference from adjacent holes was apparent.

For discharges below about 3 litres/second, a known volume was collected and the time taken noted. For the higher discharges, the braithwaite tank was calibrated volumetrically between two marks using a pointer gauge mounted on the tank. The appropriate orifices were opened and discharged into the tank and the time taken to fill a known volume measured.This was repeated until consistent results were obtained for the range of discharges required. Calibrations to within ±2 percent were obtainable in this manner.

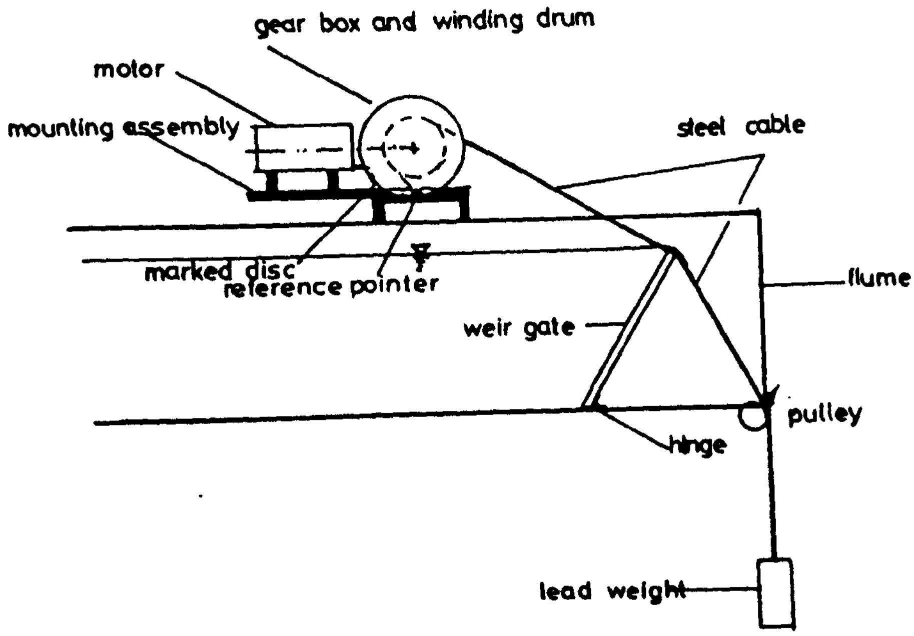
The constant head was maintained via a circular decant overflow weir. Once the correct orifices had been opened at the beginning of an experiment, the water level in the constant head tank would be set. This level would subsequently monitored with a variable conductance depth probe, installed in the tank and connected via suitable electronics to an oscilloscope. Thus, immediate warning would be given if the laboratory supply and, as a result, the discharge head changed, whilst an experiment was in progress.

The constant head tank operated at a head of approximately 500mm and this could be confidently maintained to within ±5mm, giving a discharge fluctuation from the orifices of ±0.5 percent. This ensured that series of experiments could be repeated.

Figures 3.5 and 3.6 detail the constant head supply and the mechanised tail gate assembly.



Constant Head Water Supply
Figure 3.5

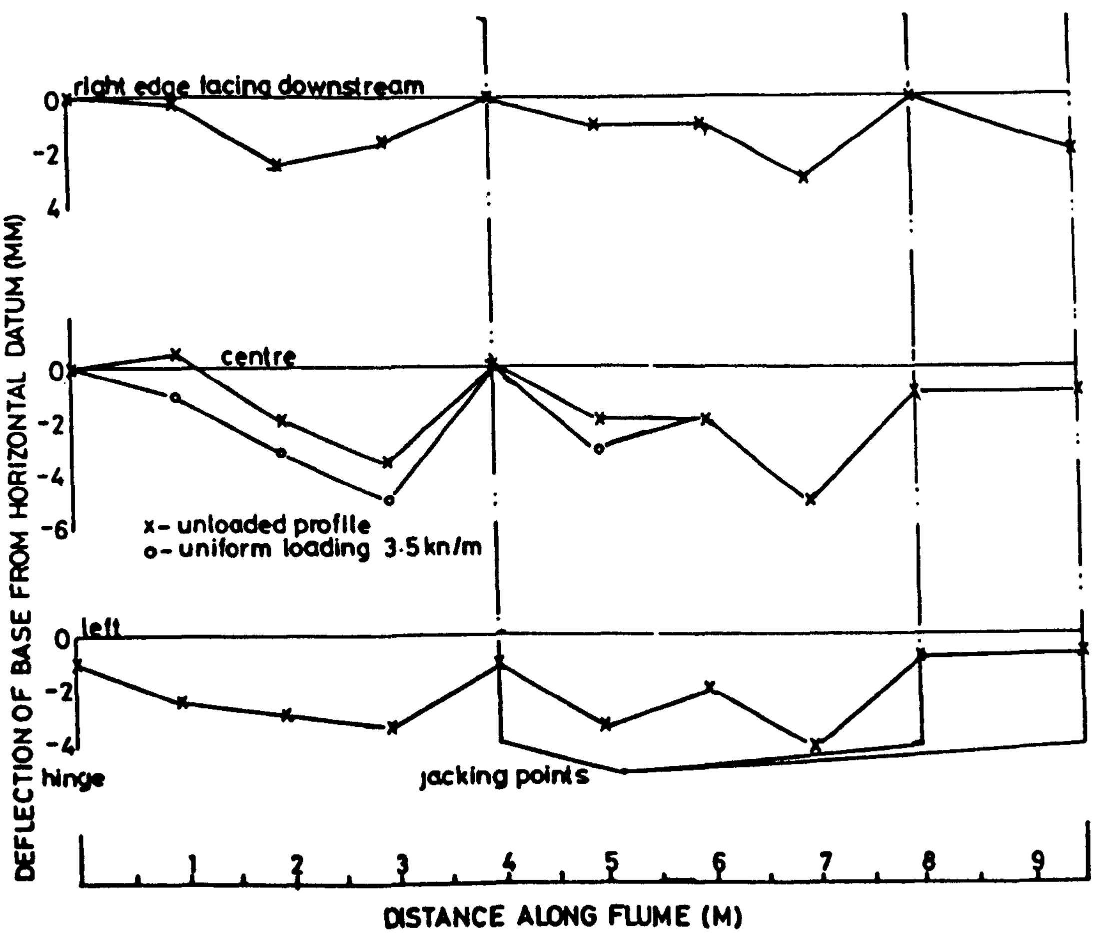


Tail Gate Mechanism
Figure 3.6

3.1.4 Live Loading Test on Commissioning of the Flume

The flume was designed to run full with water i.e. a uniform loading of 3.5 KN/metre, resulting in a maximum vertical deflection of any part of the base of less than 1mm. This was tested once the flume had been constructed and the measured deflections did not exceed this limit.Some distortion of the base of the flume had occurred from spot welding the stiffeners onto the plate but this was not a problem as the model was built into the flume and the only consideration was to eliminate any significant distortion during operation of the model.

The effect of the live loading test has been shown on a plot of bed levels before and after loading, figure 3.7 .



Deflection of Flume During Live Loading Tests
Figure 3.7

3.2 Model Construction

3.2.1 Material

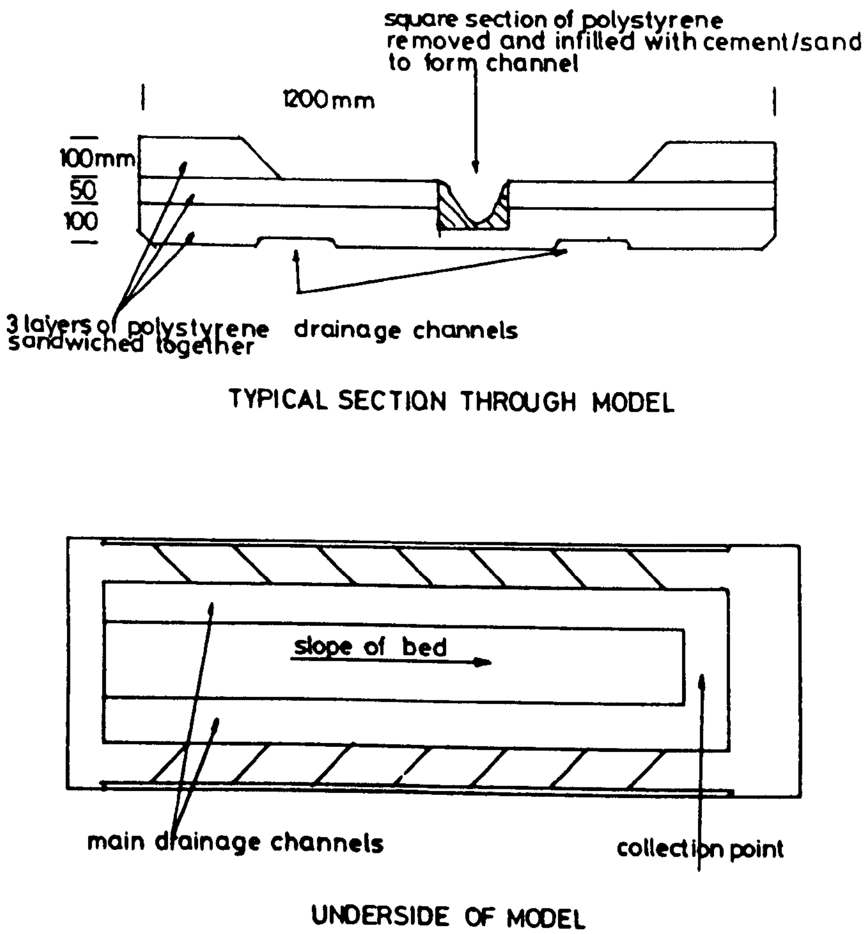
The traditional method of model construction normally uses a sand/cement mortar moulded to templates fitted into the flume.The author felt that a better way could be found and decided to adopt polystyrene as a construction material for its low weight and ability to be cut easily into specific shapes.

3.2.2 Design

The model was constructed in 3 layers of polystyrene blocks, having the same width as the inside of the flume and each layer in two lengths of 4 metres and one length of 1.5 metres.These were cut and glued to form a homogeneous material which fitted snugly into the flume. The edges and joints were sealed with a waterproof silicone rubber sealant.

The high bouyancy of the material constituted a significant danger to the stability of the model when running with water. Any model constructed from this material had to be free from water pressures transmitted to its base from water percolating either through the material or down the joints between sections, thus causing the polystyrene to lift. Therefore, the underside of the model had drainage channels cut into it,running its length. These terminated at a drainage orifice in the flume a short distance upstream of the weir gate. This permitted free drainage from any part of the base to a central drainage hole the leakage from which could be monitored.

Figure 3.8 shows the underdrainage channels and 'sandwich' design of the polystyrene model.



Design Details of Polystyrene Model
Figure 3.8

3.2.3 Construction Details

The shape of the river for the model study lent itself to construction in polystyrene as it consisted of a meandering river contained within what was essentially a flat floodplain.Thus three layers of polystyrene were used, a 100mm base layer and a 50mm layer to form the level of the floodplain with sufficient depth of material to excavate the main channel. The final 100mm layer formed the floodplain banks.

The selected section of the river (choice of reach and selection of model scales covered in Chapters 5 and 6) had been surveyed along its length and the main channel and floodplain boundaries mapped, thus fixing the model in plan. 20 detailed cross-sections had also been surveyed along this reach. The surveying office at Thames Water Authority reproduced their digitised plans to the required model scale and the author cut and stuck the sheets together to form an enlarged plan of the reach.This was used to mark out the main channel on the second layer of polystyrene which was then cut using a hot wire cutter and then glued to the bottom layer. The plan was used again to mark the floodplain boundaries on the third layer which was cut and glued on to the second layer.

The basic shape of the model had now been established and all that remained was to determine the slope of the floodplain boundary and form the cross-section of the main channel. The surveyed cross-sections were digitised and reproduced on plots of the appropriate scale . Negative aluminium templates were made from these and used to determine the final details of the model. The main channel was excavated to a rectangular shape large enough to contain each cross section. The templates were then fitted on to the model and the main channel filled in to form the correct cross-section using a sand and cement mix. The shape of channel between templates was interpolated.

The model, once complete, was painted with an oil based gloss paint to provide a water resistant surface, minimising the absorption of water and creating a tougher surface.

Finally, the model was sealed to the flume with silicone rubber sealant. During testing, the leakage along the base of the model was monitored at the drainage orifice and found to be less than 0.1 percent of the minimum discharge used.

A photograph of the model nearing completion is shown in figure 3.9 .

Photograph of Model Nearing Completion

Figure 3.9

3.3 Instrument Carriage and Probe Locating Assembly

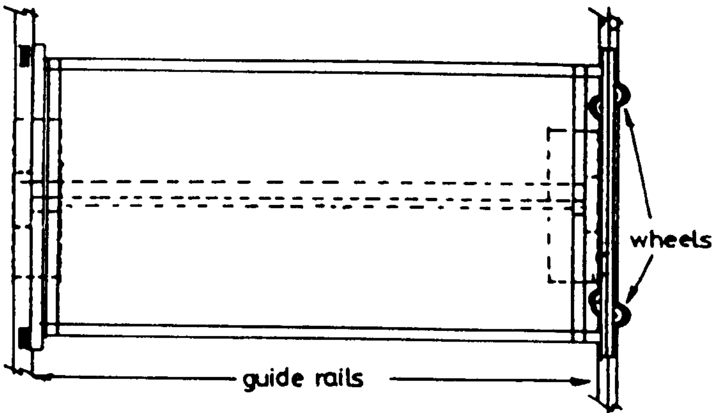
3.3.1 Guide Rails

25mm x 25mm aluminium angle section rails were mounted on the horizontal flanges of the flume using 6mm diameter adjustable threaded rods fixed to them at 600mm centres and secured to the steel flange of the flume with two nuts. This enabled the rails to be levelled accurately. One guide rail was mounted with one flange horizontal along which the wheels on one side of the instrument carriage would run. The other guide rail was mounted with its flanges at 45 degrees to the vertical and the apex facing upwards. This provided a base along which the sets of wheels on the other side of the carriage, mounted at 45 degrees, would run, thus ensuring precise kinematic location along the flume.

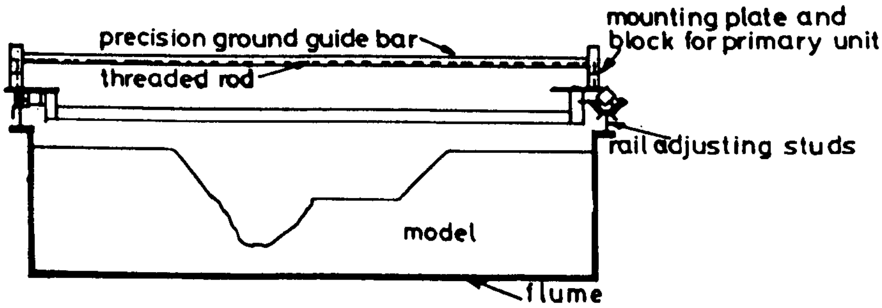
3.3.2 Instrument Carriage

A rectangular frame spanning the flume and about 600mm wide, made from lengths of 25mm square hollow steel section formed the skeleton of the instrument carriage. Horizontal steel plates were bolted on each end of the carriage to support the probe positioning assembly.

Figure 3.10 shows the instrument carriage mounted on the guide rails.



PLAN OF INSTRUMENT CARRIAGE WITH MOUNTING ASSEMBLY SHOWN DOTTED



ELEVATION OF INSTRUMENT CARRIAGE AND MOUNTING ASSEMBLY

Details of Instrument Carriage
Figure 3.10

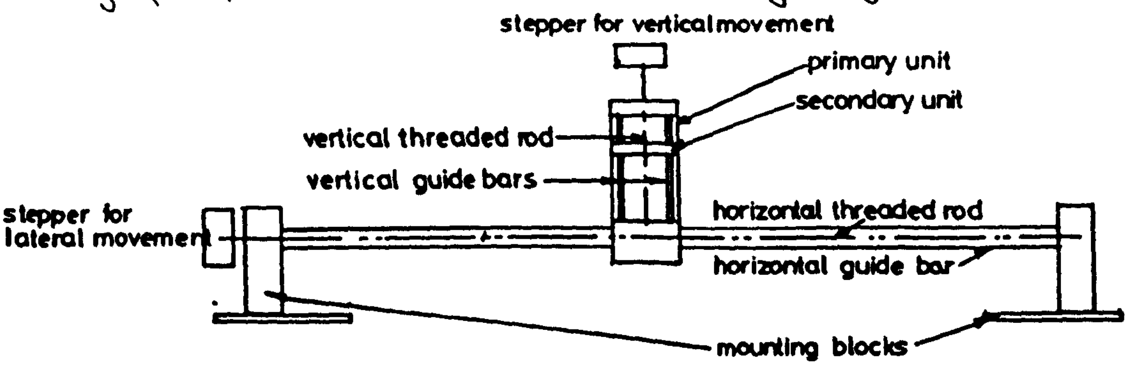
3.3.3 Probe Positioning Assembly (PPA)

An automated positioning device, largely designed by the author, (a 3-dimensional version of a 2-dimensional plotter) was built to enable a measuring probe to be automatically positioned within the flume. The mechanical parts of the PPA, consisted of a probe holder (the secondary unit) which was constrained to move vertically within a mobile frame (primary unit). This primary unit could move horizontally, laterally across the flume. Thus, with the instrument carriage free to move along the flume, upon which the PPA was mounted, a probe could be positioned anywhere within the flume.

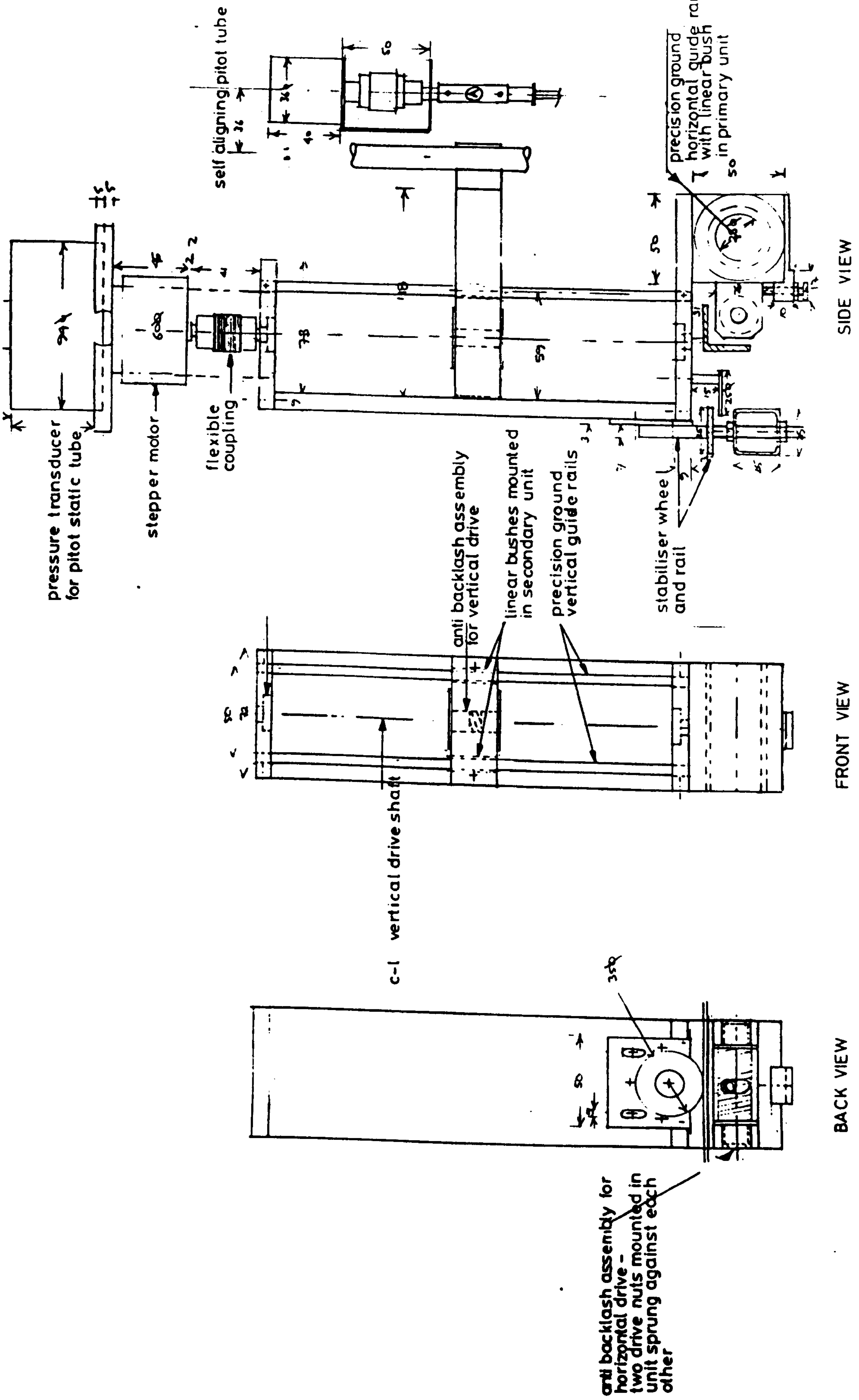
A horizontal drive rod mounted in the end blocks of the PPA could position the primary unit whilst a vertically aligned drive rod within the primary unit could position the secondary unit with respect to the primary unit.

Precision alignment of the secondary unit, the probe holder, could be maintained throughout this process by two linear bushes mounted within it running on two vertical, parallel, precision ground guide bars fixed into the primary unit. The primary unit was, in turn, constrained by a linear bush fixed into it and running on a horizontal guide bar, fixed on to the end blocks of the PPA.

Figures 3.11 and 3.12 show a block layout and more detailed views of the primary and secondary units of the probe positioning assembly. Photograph & automated data collection carriage. Figure 3.12b



Block Layout of Probe Positioning Assembly
Figure 3.11



Details of Primary and Secondary Units
Figure 3.12

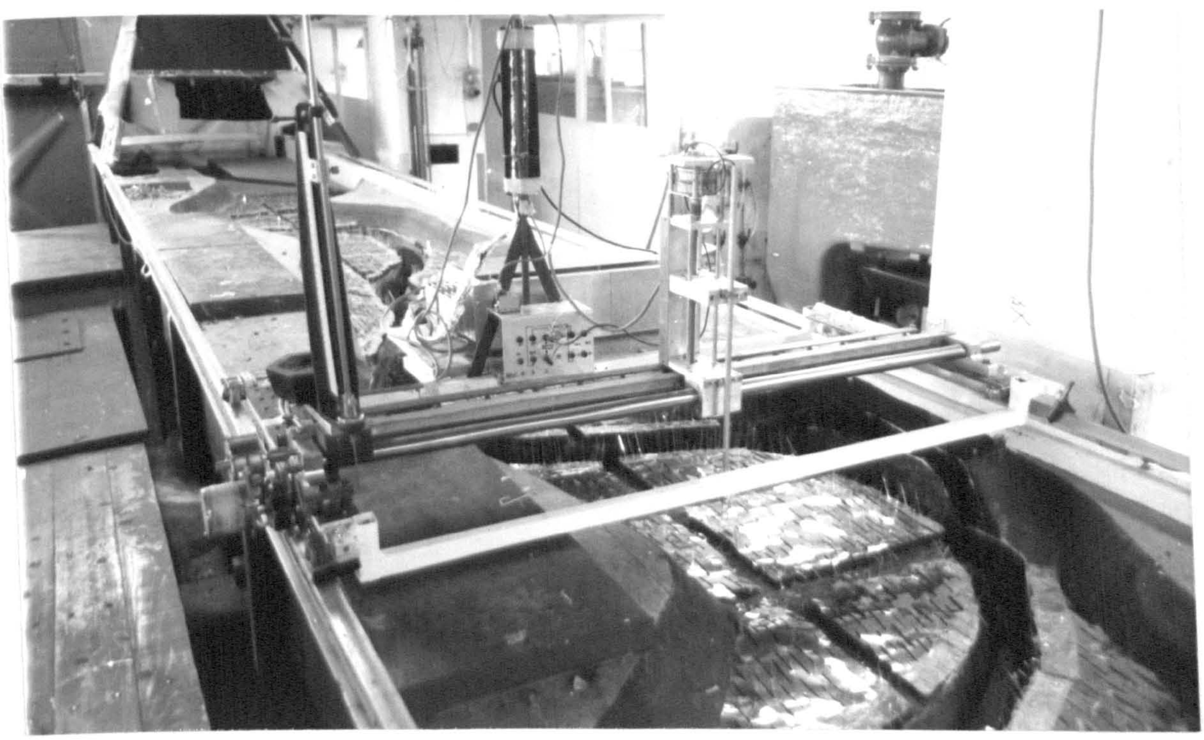


Figure 3.12b
Photograph of Automated Data Collection Carriage

3.3.4 Automated Positioning

A stepper motor, mounted on the instrument carriage and geared to one of the instrument carriage wheels, could position the carriage anywhere along the flume. Positioning of the probe head across a section could be achieved by controlling two stepper motors connected to the horizontal and vertical threaded rods of the positioning assembly.

The motors were controlled from a BBC microcomputer via linear translators which in turn controlled the movements of the motors.

The microcomputer was connected to the control side of the translators with a ribbon cable running 8 lines from the user port of the BBC. Two lines were required for each stepper motor translator, thus 6 of the 8 lines from the BBC were in operation. One provided information on direction and would be set 'high' at 5 volts or 'low' at 0 volts. The second line, when pulsed from 'high' to 'low' or 'low' to 'high, would cause the motor to execute 1 step. Thus successive changes in voltage level on the appropriate line would cause the motor to multiple step. The 'high' or 'low' states of the lines were determined by the value stored at the user port address. Each of the 8 lines represented one bit of a 1 byte value. Thus, storing a 1 byte value at the port address would set the lines according to the binary representation of that number i.e. if 68 in decimal were stored it would represent 01000100 in binary meaning that counting from the right hand digit as zero, lines 2 and 6 would be set 'high' and the remaining lines set 'low'. The means by which this could be utilised to operate the steppers in a more or less continuous mode will be described in chapter three.

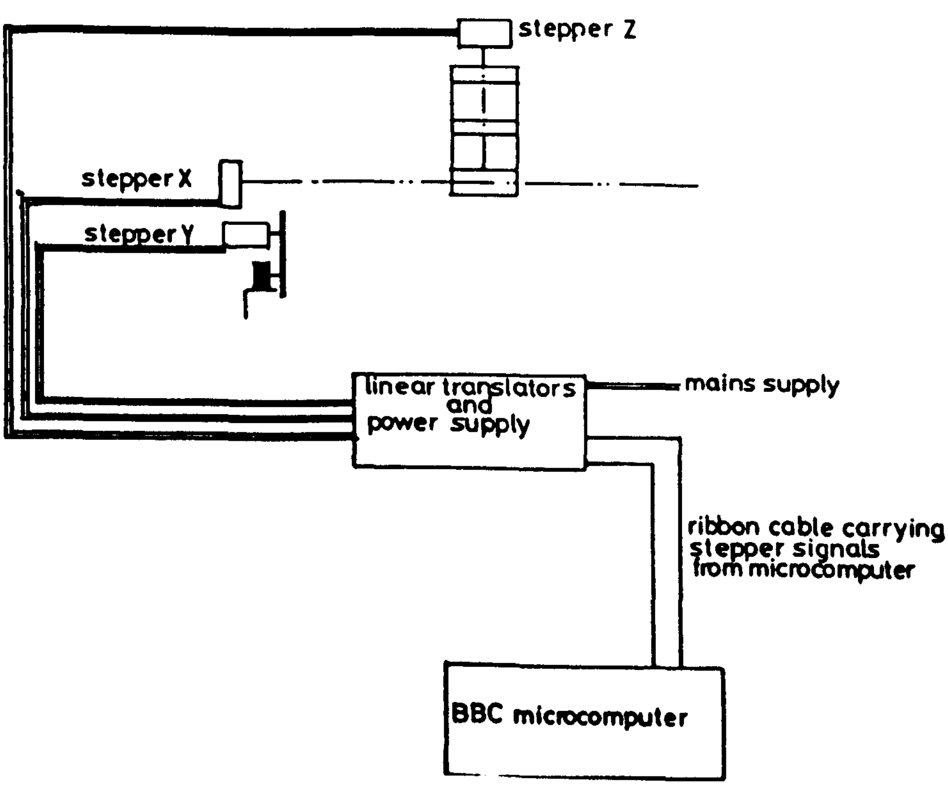
The stepper motors and translators used were bought from McLellan Servo Supplies (U.K.). The hardware consisted of three translator cards, together with a power supply, mounted in a rack system, mounted on the instrument carriage. The steppers were:

2No. ID27-101 48 steps/revolution maximum working torque 11Ncm, for the lateral and vertical positioning of the probe positioning assembly.

1No. HR23-101 200 steps/revolution maximum working torque 38Ncm for driving the instrument carriage along the flume.

All three were driven by 3No. EM162 translator modules.

Figure 3.13 shows the block layout of the stepper motors, translators and BBC microcomputer.



Layout of Steppers, Translators and BBC microcomputer
Figure 3.13

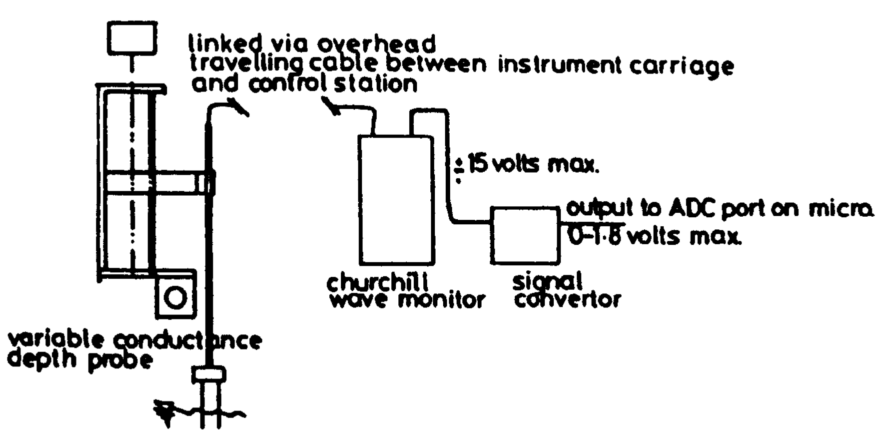
3.4 Measuring Instruments

3.4.1 Water Surface Levels

Surface levels, both in the constant head tank and in the model during an experiment, were recorded in two ways. The first, a pointer gauge with a vernier scale reading to 0.1mm, was the conventional method, used together with a more versatile device, a variable conductance depth probe. This second device consisted of a pair of parallel stainless steel wires, partially immersed in the water, about 12mm apart and each 1.5mm diameter, connected to a Churchill Wave Monitor.

The probe works on the principle of measuring the current flowing in the probe which is energised with a high frequency square wave voltage thus avoiding polarisation effects at the wire surfaces. The wires dip into the water and the current that flows between them is proportional to the depth of immersion. The current is sensed by an electronic cicuit which produces an output voltage proportional to the instantaneous depth of immersion. In this way, from a reference datum established by use of the pointer gauge, subsequent water levels relative to the start position can be evaluated by the readings received from the probe.

The probe sensitivity, typically between 1 volt/mm and 0.1 volt/mm could be adjusted at the wave monitor. This would give a full scale range on the ADC convertor of between 20mm and 200mm.



Depth Probe, Churchill Wave Monitor and Signal Convertor
Figure 3.14

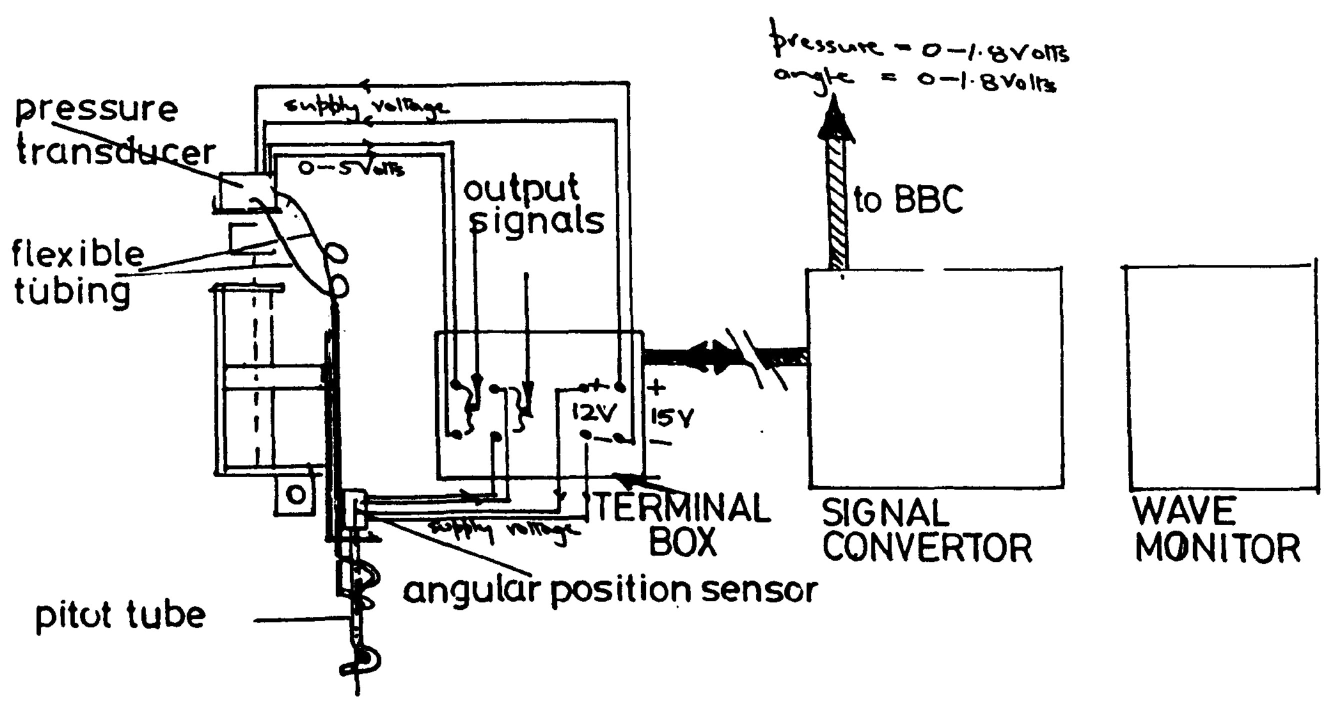
3.4.2 Flow Velocities

The author designed a self aligning pitot-static tube for measuring water velocities in the model. The instrument took the shape of a thin pitot-static tube,3mm outside diameter,about 100mm in length and bent to accomodate a fin at the bottom of it. The fin was fixed behind the centre-line of the vertical shaft about which the whole assembly rotated.

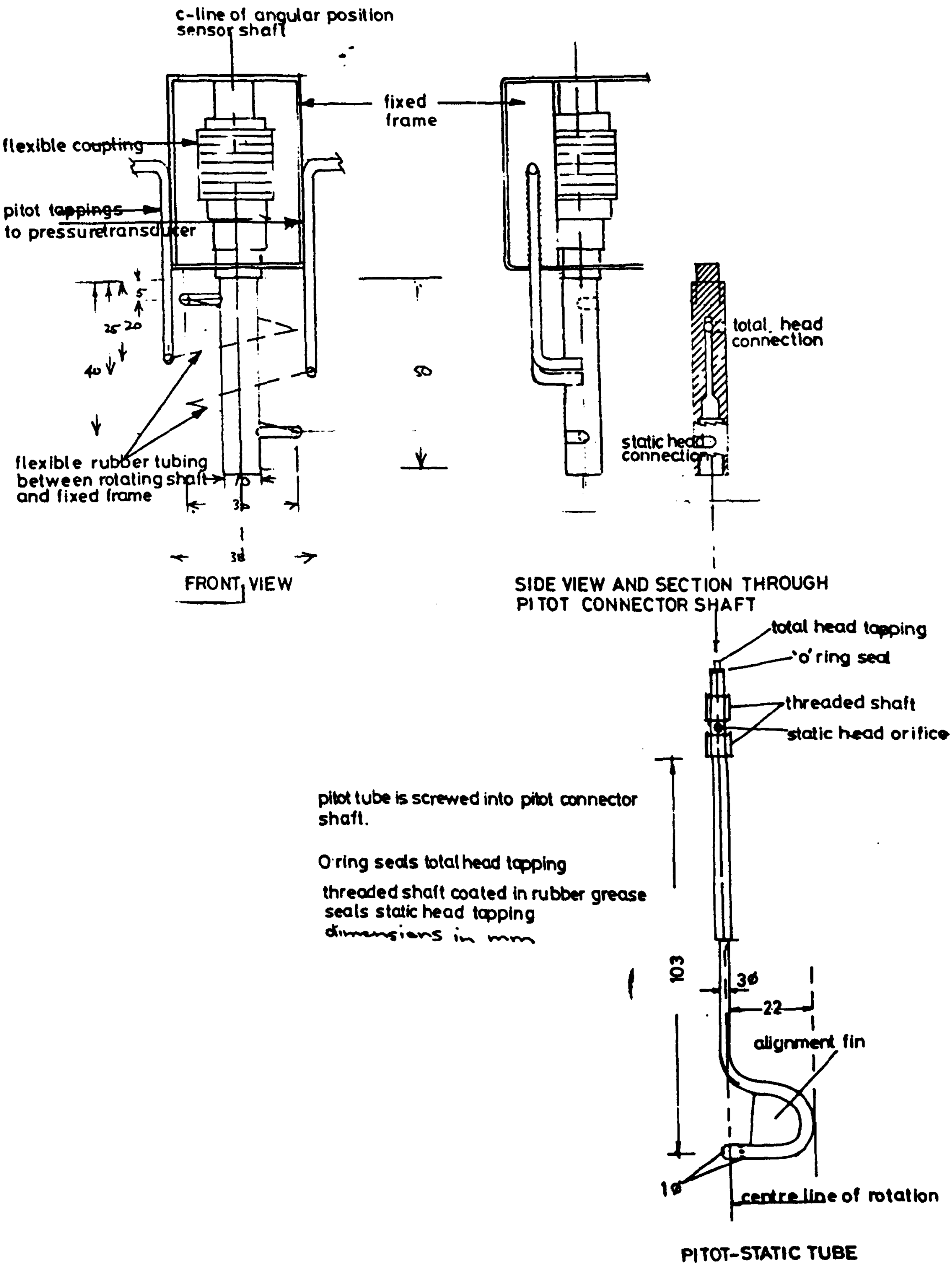
The layout of the pitot-tube, transducers and electronic components is given in figure 3.15 .

Details of the self-aligning pitot tube are shown in figure 3.16 .
Photograph of primary + secondary units with pitot attached, figure 3.16b

The photograph in figure 3.17 shows the terminals box, Churchill monitor and signal convertor.



Layout of Pitot-Tube, Transducers and Electronic Components
Figure 3.15



Details of Variable Yaw Pitot-Tube
Figure 3.16

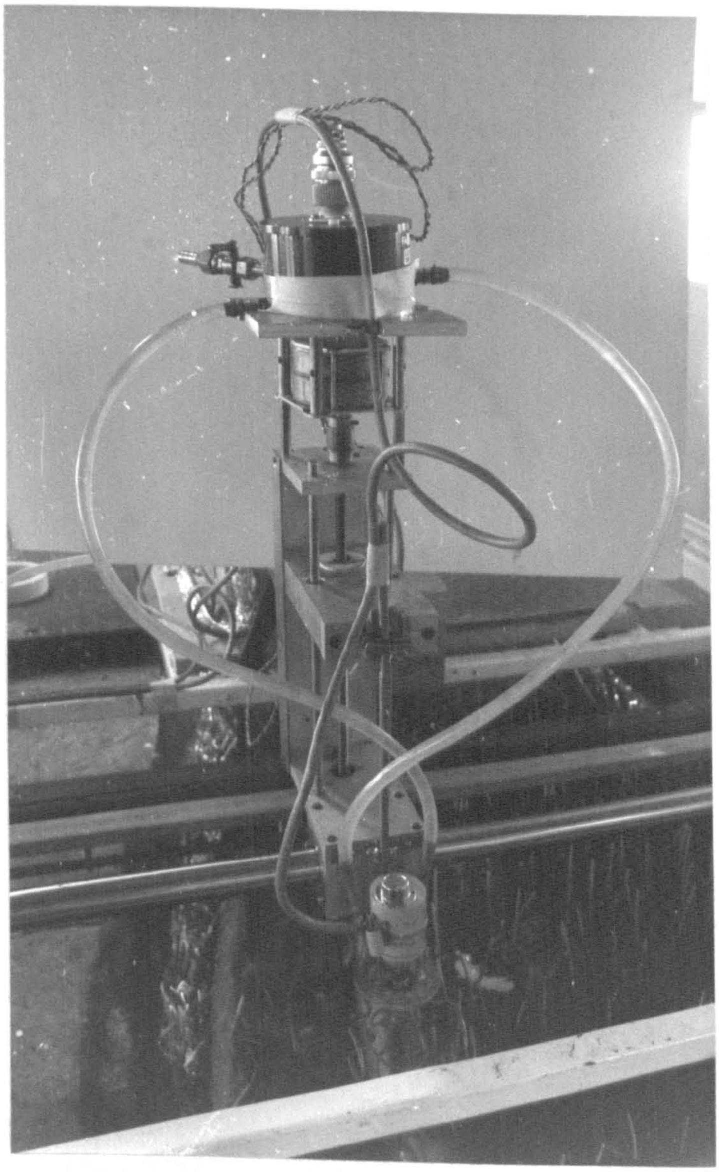
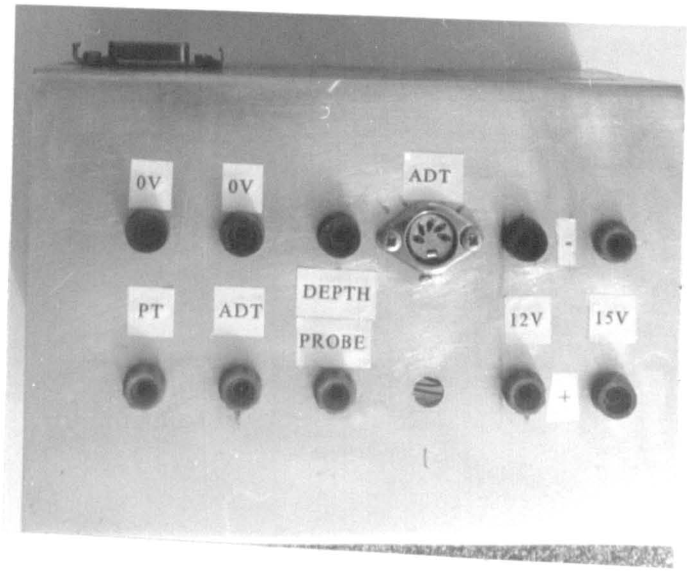
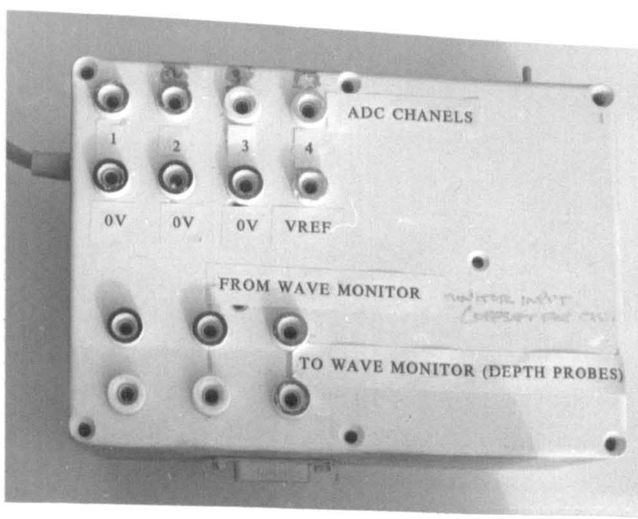


Figure 3.16b
Photograph of Primary and Secondary Units
with Variable Yaw Pitot Tube Attached





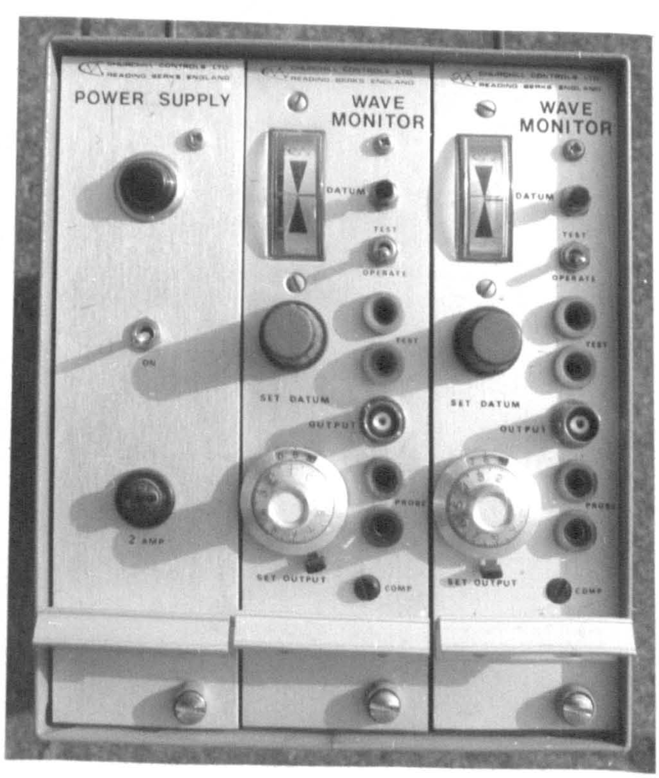
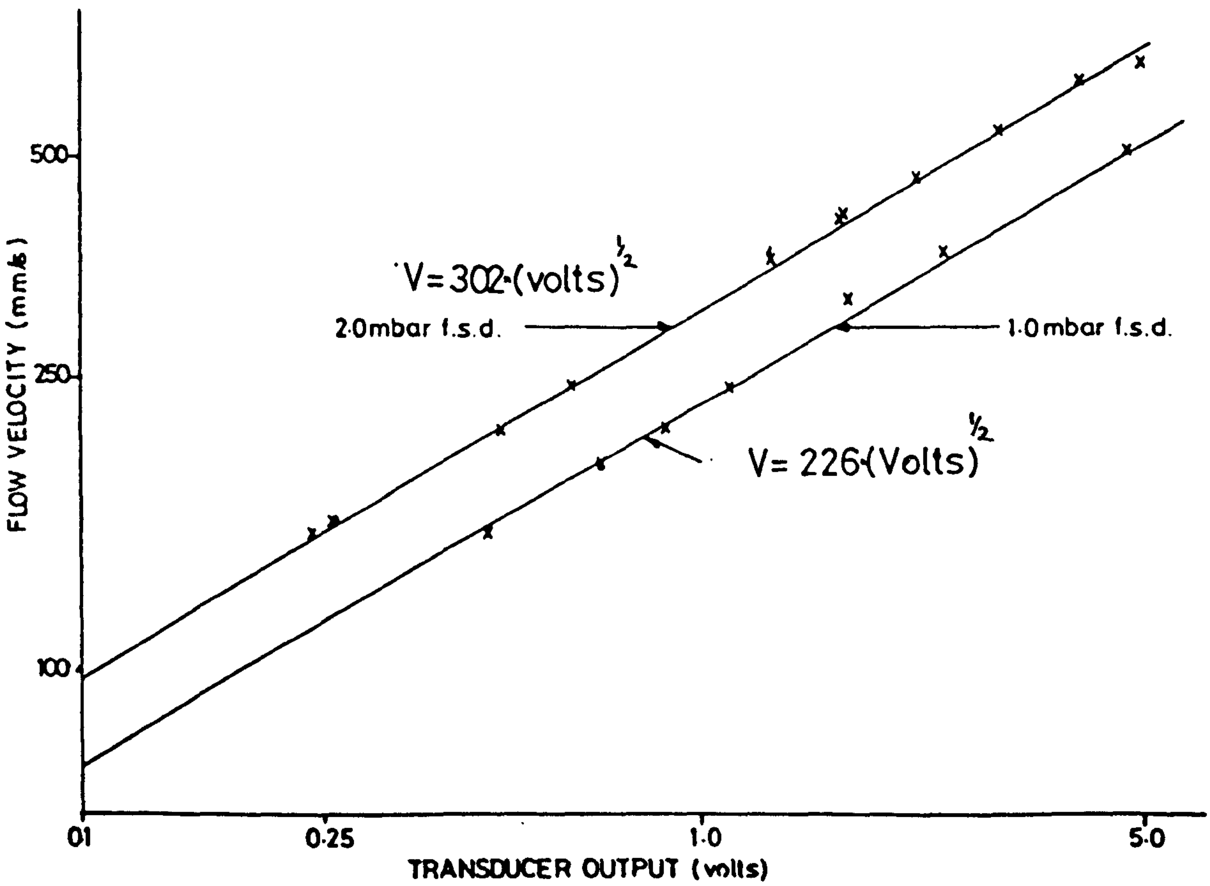


Figure 3.17
Photograph of Terminal Box,Signal Convertor and Churchill Wave Monitor

The low dynamic heads generated were measured with a low displacement pressure transducer mounted with the diaphragm horizontal. Velocities between 40mm/s and 600mm/s could be measured depending on the working range of the pressure transducer used.

Three bi-directional pressure sensors were available for use on the rig, having a full scale range of 0.5 mbar, 1.0 mbar and 2.0 mbar. These were purchased through Sandhurst Scientific Instrument Company (U.K.) .

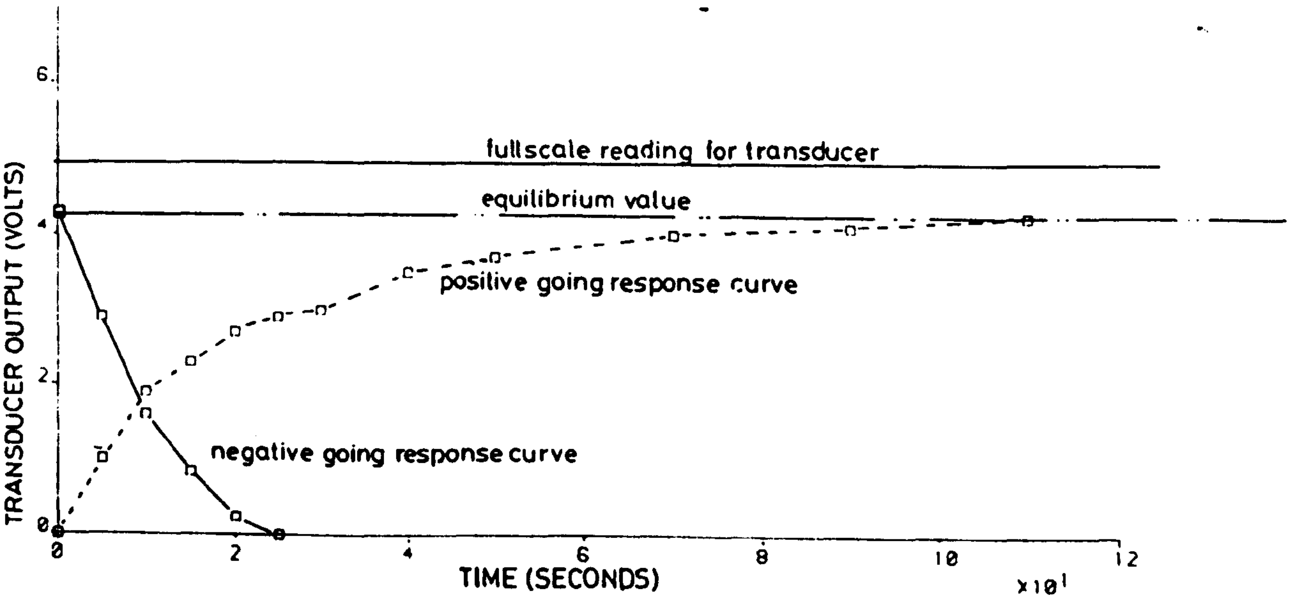
Figure 3.18 shows a plot of flow velocity in mm/s vs transducer output in volts for the 1.0mbar and 2.0mbar transducers.



Log. Plot of Flow Velocity vs Transducer Output With Pitot-Tube Connected
Figure 3.18

These Elec Torr FA76 series of very low pressure sensors had a maximum volumetric displacement of less than 0.05 millilitres and a line pressure limit of 50 bar. The overpressure limit for the 0.5 and 1.0 mbar units was 100 mbar and 700 mbar for the 2.0 mbar unit. Therefore care had to be taken not to exceed the pressure whilst de-airing them prior to use. A loop supply voltage of between 10 to 30 volts was recommended with a linear output between +5 and -5 volts. De-airing was a quick and simple process and no trouble was encounterd with false readings due to trapped air within the transducer unit.

The response curves for the 1.0 mbar unit connected to the pitot-tube and recording dynamic heads in water have been plotted in Figure 3.19.



Response Curve for Pitot-Tube
Figure 3.19

The angular displacement of the probe was measured with a linear angular position sensor mounted axially over it.

A Penny and Giles potentiometer was used, type D3810/300. The required input is a nominal stabilised 10v d.c. from a source impedance of less than lohm. The d.c. input is converted to an a.c. waveform by an integral oscillator and then fed to a transformer primary winding. The output from the secondary winding is converted to d.c. by an integral demodulator and filter.

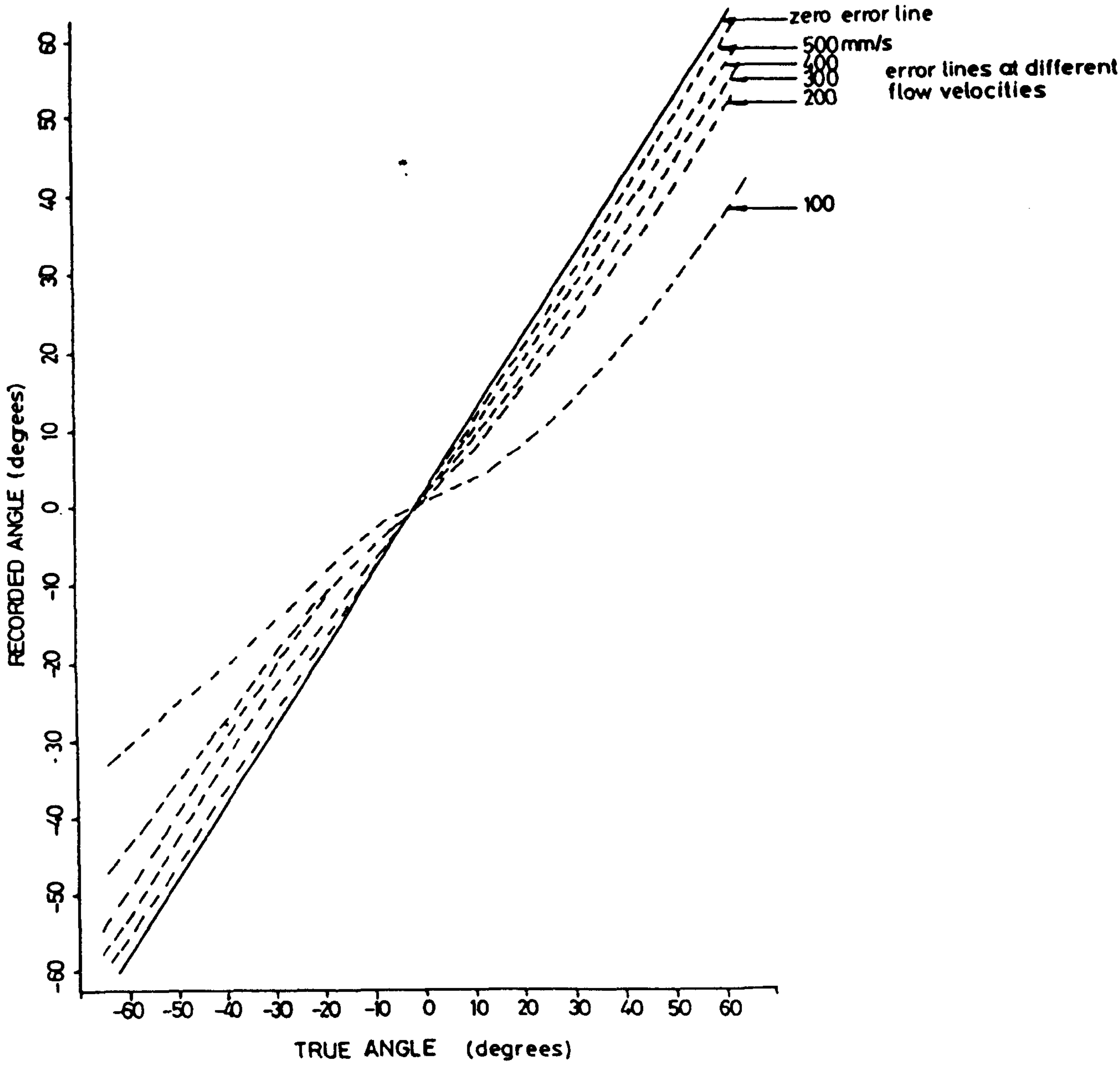
The angular position sensor used provided a linear voltage output over a 300 degree angular range.

The design of the self-aligning probe was such that the probe could not completely align itself with the flow . This was on account of the elasticity of the rubber tubing resisting rotation of the probe head.Therefore, it was necessary to calibrate the error generated for the range of velocities and angles of incidence likely to be encountered.

To do this, the pitot tube was mounted in a parallel sided flume together with a low speed Streamflo Novar propellormeter which had previously been calibrated in a towing tank. The probe was immersed in water with flow velocities ranging from 10-60 cm/s and a range of incident angles from -60 to +60 degrees. From this experiment a correction matrix of true angle/recorded angle for the entire range of speeds was built up. Thus the recorded angle of incidence from the experiment could be corrected to produce a more accurate value.

No velocity corrections were made for the pitot tube for misalignment in the flow direction. Tests demonstrated it was relatively insensitive to deviations of up to 15 degrees from the true direction for measuring the correct magnitude of velocity. Rajaratnam, in his technical note on "The Prandtl Tube as a Preston Tube" **(54)** found that for a dynamic pressure error of less than 5% (a velocity error of 2.5%) the misalignment of the tube from the flow direction would have to be less than 15 degrees.

Figure 3.20 shows the results of the calibration test and Table 3.1 sets out the correction matrix used in adjusting the results.



Calibration of Variable Yaw Pitot-Tube
Figure 3.20

Velocity (mm/s)	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60
600	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60
500	-60	-50	-40	-30	-20	-10	0	11	20	30	40	50	60
400	-60	-50	-43	-30	-20	-11	0	11	20	30	40	50	60
300	*	-57	-47	-35	-25	-11	0	14	25	33	47	56	*
200	*	*	-53	-41	-30	-15	0	15	28	38	51	*	*
100	*	*	*	-52	-36	-19	0	27	40	54	*	*	*
0	*	*	*	*	*	*	*	*	*	*	*	*	*

recorded angle (degrees)

Table 3.1
Correction Matrix for Variable Yaw Pitot Tube Angular Displacement
Matrix Contains True Angle of Rotation

CHAPTER 4

INSTRUMENTATION

This chapter describes the computer software which was used to control the experiments carried out on the river model. A BBC model B 32k RAM microcomputer fitted with an Aries B-32 32k RAM expansion board and a 3.25 inch disc storage system using cassettes with a storage capacity of 100kbytes/side formed the core of the computer hardware. The BBC User Guide (52), the Advanced User Guide for the BBC Micro (51) and Advanced Disk Users Guide (53) were used extensively in developing the Basic and assembly language programmes.

For the purposes of investigating the characteristics and behaviour of the model, three programme modules were written to assist in the construction of:

1. Depth-Discharge curves.
2. Mean Point Velocities through cross-sections of the river.
3. Isometric views of the free water surface.

These all require the measurement of either velocity of flow, surface levels or both. Recording water surface levels to produce a family of drawdown and backwater profiles for depth-discharge curves, would normally be carried out using a pointer gauge mounted on the instrument carriage, positioned and read manually. The readings and corresponding positions would be entered in a log book. Measuring point velocities is a more complicated task, using either a miniature propellormeter or pitot-static tube. The grid position of the probe within the cross-section would have to be recorded and together with the output from the probe.

The software developed during the period of experimental work in the laboratory precluded the need for time consuming and tedious manual measurements such as those described above. This has facilitated a more and varied experimental programme which otherwise could not have been considered.

Covered in this chapter is a description of the operating software to investigate the three topics mentioned above.

Listings of all programmes described here can be found in appendix A.4 .

4.1 Stepper Motor Control and Data Collection

The strength of the automated data collection system lies in the ability of the operator through the computer and its software, to control in a predetermined fashion, the position of the probe head with the stepper motors. Chapter three has dealt with the mechanics of the stepper system and here the author will elaborate on how the stepper motors are pulsed from the computer.

There are a number of external sockets on the BBC microcomputer via which the machine can communicate with the outside world or vice versa. The ones of particular interest are:

1. user port
2. analogue to digital convertor input (ADC)
3. RS423 interface

The first and second sockets are used whilst an experiment is running. The user port sends information to the linear translators (described in chapter 3), which in turn pulse the stepper motors by energising the appropriate coils within them. The ADC receives analogue voltage signals from the measuring equipment and converts them into digital values which are then passed on within the computer for storage or processing. The third socket enables the computer to act as a 'dumb' terminal, communicating via a Peripheral Access Device (PAD) line to other computers. This is used for transferring data from the storage disc connected to the microcomputer to a larger computer for more complex processing and analysis.

The user port has 20 lines, 10 of which are earthed,2 are control lines and 8 are data lines. The user port is connected to the linear translators via a 20 way ribbon cable. The earth lines are connected alternately between the data lines to act as a 'sink' shielding them from stray electric fields which could corrupt the signal travelling down the lines. As previously mentioned in chapter two, 6 of the 8 data lines are used to control the stepper motors. The 8 lines each correspond to 1 bit of an 8 bit byte. The values of each of these bits is determined by a 1 byte value which can range between 0 and 255. This would correspond to 0000 0000 and 1111 1111 in binary, meaning that all the lines would be set to 0 volts or all set to 5 volts. The address at which a value can be stored to control the state of these lines is at location Hexadecimal FE60.

As an example, stepper X is considered. The controlling lines for stepper X are 0 and 4, ***1 ***1 . The least significant bit, the rightmost, is bit 0. This line controls the direction of the stepper, if it is set at 1 the motor will rotate clockwise the next time it is pulsed. If it is set to 0,the motor will rotate anticlockwise. Counting from the right, bit 4 controls the pulsing.The remaining bits, marked as *'s do not affect stepper X. To pulse continously, the state of bit 4 must switch from 'low' to 'high' continuously. Changing the state of bit 4, in either direction will make the motor execute one pulse.

Included here are some short lengths of assembly language instructions from a working programme to illustrate best how the operation works. PORTB represents the user port location, hexadecimal FE60.

	description of operation	PORTB value
a)		
LDA £&01)		
ORA PORTB)	perform logical OR on each bit	**** ***1
STA PORTB)	sets bit 0 to 1	
b)		
LDA £&FE)	perform logical AND on each bit	**** ***0
AND PORTB)	sets bit 0 to 0	
STA PORTB)		
c)		
LDA £&10)		
ORA PORTB)	perform logical OR on each bit	***1 ****
STA PORTB)	sets bit 4 to 1	
d)		
LDA £&EF)		
AND PORTB)	perform logical AND on each bit	***0 ****
STA PORTB)	sets bit 4 to 0	

The other bits marked * during an operation are unchanged therefore it is possible to execute these instructions in a programme to control the steppers independently of the others. Segments a) or b) would be used at the start of a run to determine the new direction of the stepper motor. Segments c) and d) would be used alternately to multiple step the motor.

Thus, a typical simple sequence would be:

a) or b) to set up direction followed by
c)-delay-d)-delay-c)-delay....until the required operation had been carried out. The delay routine would be necessary to control the speed of the motor.

4.2 Setting Up

The procedure for setting up the water level and velocity recording instruments is covered in this section. A detailed description of the instruments can be found in chapter 3.

4.2.1 Water Level Probe Calibration

Before use, the depth probe needs to be calibrated to relate the digital reading from the ADC to the degree of submersion of the probe wires. There are two main factors which could change the calibration coefficient of the probe. The first is the drift of the signal amplifiers, which on account of the equipment remaining on all the time, is insignificant. The second could be due to changing the gain of the wave monitor. This would be done if the sensitivity of the probe needed to be adjusted depending on the variation of water level expected down the flume before the start of a run.

The probe can be easily calibrated whilst still in place in the flume. Programme, CALIB, enables the coefficient relating submersion to a digital output to be evaluated. The operator must place a beaker of water beneath the probe before running the programme . Once running, CALIB, immerses the probe automatically into the water whilst recording the depth of immersion, and the output signal from the probe monitor on the ADC. The depth of immersion of the probe is related to the number of angular steps executed by the vertical stepper motor.

The probe is lowered at a constant rate by the stepper motor and a number of readings taken at various stages of immersion. The result is plotted to check the linearity of the probe output and averaged to give a final calibration coefficient which can be used in the experiment. Resolution to within 0.1mm is easily acheived with this type of probe.

4.2.2 Variable Yaw Pitot-Tube De-airing and Calibration

The variable yaw-pitot tube is used in determining time averaged point velocities across a section of the model. Before commencing a run, it is necessary to ensure the pitot-static tube has been de-aired, that the pressure transducer is operating and to calibrate the Angular Position Sensor (APS), which measures the yaw of the pitot tube.

Programme ADVAL performs these functions by enabling the operator to calibrate the APS and confirm by way of a screen plot and digital displays whether the pitot tube is operating normally.

4.3 Depth-Discharge Curves

Depth discharge curves for the model, for various roughness states have been built up by considering the backwater and drawdown curves over the range of appropriate discharges. From these families of curves, it was possible by inspection to establish the uniform condition and thus find a representative depth of flow for each discharge used.

Two programmes, LONGBAS and LONGMC, the first written in basic and the other in assembly language control the operations which produce the family of M -curves.

The time taken in collecting and plotting data by hand for one profile when attempted in the early days of the research programme took up to half an hour. With the development of this software and the automated instrument carriage, the time taken to collect data for each profile is about 4 minutes. Furthermore, it is always difficult to obtain a mean surface level in a body of highly turbulent fluid using a pointer gauge . In the author's method a large number of instantaneous readings are taken and averaged.

The secondary unit of the Probe Positioning Assembly is fitted with the variable conductance depth probe, see Figure 3.14, and the instrument carriage, driven by the Y-coordinate stepper motor, traverses the length of the flume. During this operation the microcomputer stores depth readings at fixed positions down the flume, measured by the partially submerged depth probe. These readings are taken relative to the level of the instrument carriage guide rails.

It is necessary to produce an averaged water surface level for a longitudinal profile,eliminating the surface fluctuations due to turbulent effects within the body of fluid.The instrument carriage does not stop, however, whilst readings are being recorded from the probe. Thus time averaged values at individual locations cannot be established. However, its slow rate of travel down the flume , about 30mm per second, enables a group of readings to be taken and time averaged over a fairly short distance with a total sampling time of a few seconds.

Up to 200 readings can be taken over a 100mm traverse and time averaged to one reading representing the centre point of the segment.Thus, localised surface disturbances such as small standing waves due to irregularities of the model and surface level fluctuations, varying at a rate greater than about 0.3 Hz, are eliminated.

At the start of a run, there is an option to record averaged readings relative to the floodplain or to a horizontal datum i.e. absolute values. This is possible with correction data stored within the programme.These data have been produced from a detailed levelling exercise on the instrument carriage guide rails and floodplain which was constructed as a plane surface.

Each family of curves are related to each other by measuring the water surface level with a pointer gauge mounted on the instrument carriage at the start position of the depth probe before each traverse. At the end of each traverse the current profile is plotted on the screen then, if acceptable, the levels are stored on disc together with the discharge, gate setting and spacing between averaged readings. The procedure is repeated for different gate settings until sufficient longitudinal water surface profiles have been produced. The discharge can then be altered and the process repeated. If the operator needs to terminate the run prematurely without crashing the system, an <escape> facility has been built into the software. Pressing the <ESC> key whilst a run is in progress will terminate the run and control will return to the operator via the keyboard.

Once an entire set of data have been collected on the storage disc it is ready for further processing and plotting on a main frame computer with advanced graphical routines. A simple Fortran programme using resident plotting packages produces plots of the type in appendix A.6, a sample of which is given in Figure 4.1 .

4.3.1 Flow Charts

The operators instructions follow:

1. Calibrate Depth Probe - using programme CALIB
2. Enter Initial Parameters into computer
3. Set Discharge
4. Set Gate
5. Set Instrument Carriage at start of run
6. Adjust depth probe
7. Read Pointer Gauge at probe position
   (At start take floodplain level reading as well)
8. Engage Y-coordinate stepper gear
9. Enter run details into computer

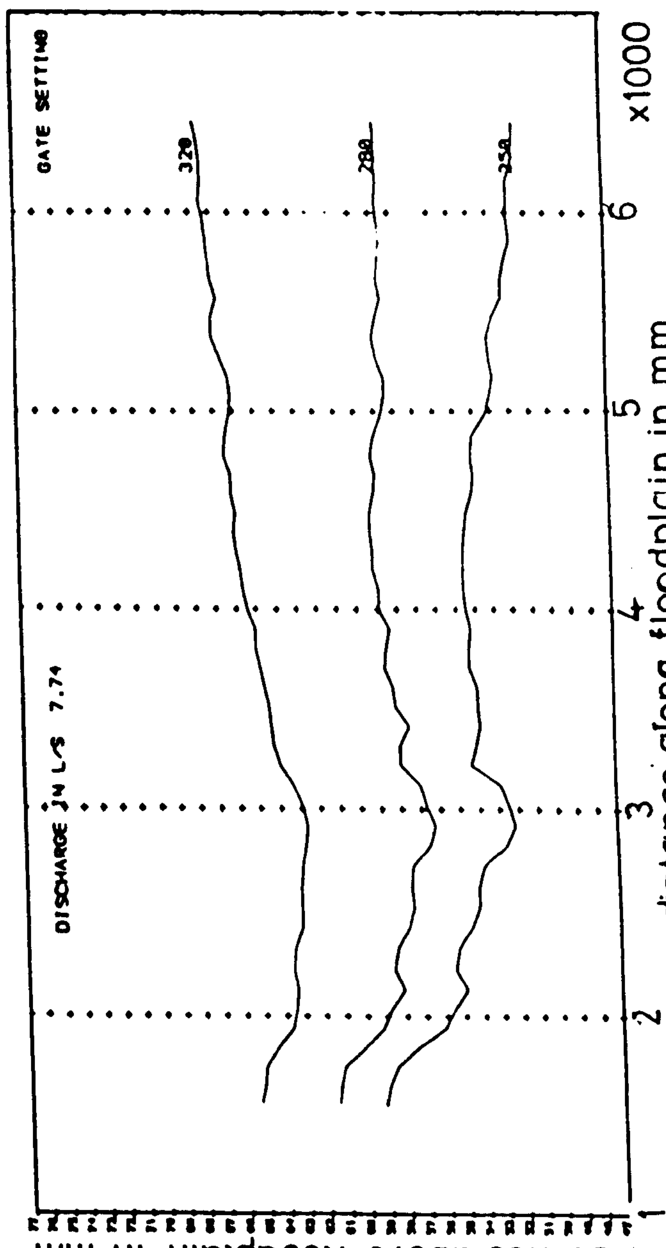


Figure 4.1
Plot of Longitudinal Water Surface Profiles

10.Start run

11.Run finished:

a) Scrap run GO TO 4

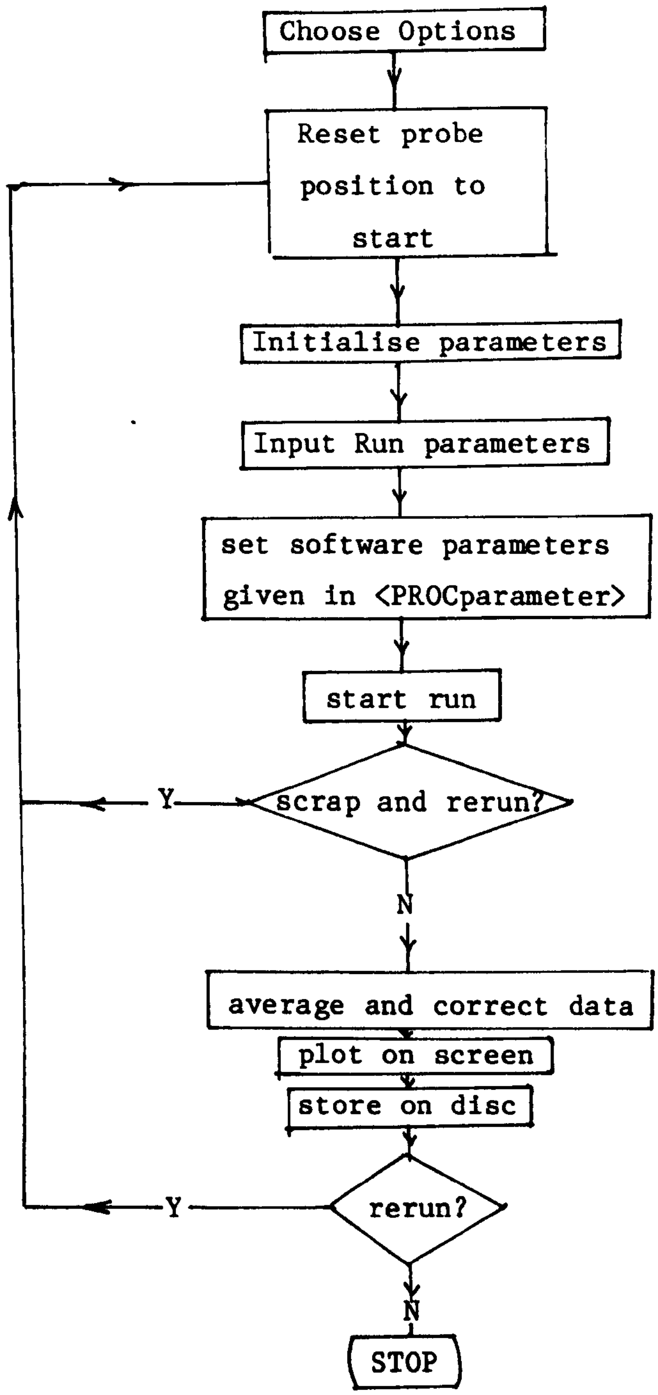
b) Plot and store run GO TO 12

12.Change Discharge - GO TO 2

13.Change Gate - GO TO 3

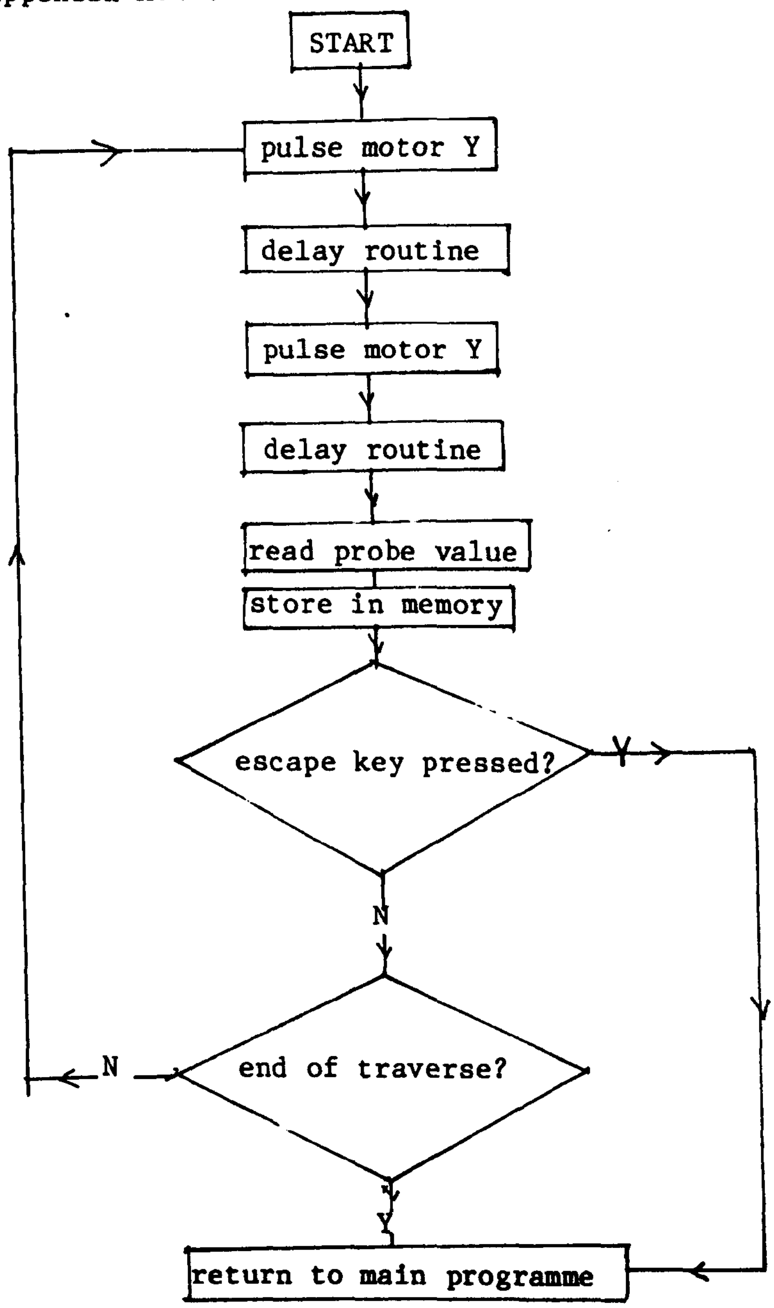
14.Stop

Below is a flow diagram for **LONGBAS** :
The numbered boxes relate to programme sections listings of which can be found in appendix A.4 .



The following flow diagram outlines the main operations carried out within the assembled version of **LONGASM** .

The numbered boxes relate to programme sections listings of which can be found in appendix A.4 .



4.4 Velocity Profiles

The most sophisticated software developed during the project has been that written to record time averaged point velocities in a grid pattern across any section of the model, in the main channel as well as the floodplain. The stored data could then be processed to produce contours of constant velocity in the principal direction of flow. This software was developed primarily for the same reasons as for the programmes mentioned above. The time involved in manually traversing a probe across the flume, taking measurements by hand and later entering them into a computer for plotting was prohibitive. Not only would the two coordinates fixing the position of the probe have to be measured together with the appropriate velocity and angle readings but they would all have to be enterd manually into a data file. As a rough rough guide, approximately 300-400 readings were taken across any given section of the model, the number of readings taken dependant on the size of cross-section and depth of flow. The time taken to perform this operation using the automated rig system is between 2 and 5 hours. To carry out the same task manually, an operator would be completely tied up during the measurements and would have to enter the values manually. This could take anything up to an extra 3 or 4 hours. With the automatic system, the operator need not be present during the run and so his time can be spent elsewhere. Some particularly long runs requiring up to 800 readings were left overnight unattended.

As explained in chapter three a self aligning pitot static tube was developed for this project which was fitted to the secondary unit of the Probe Positioning Assembly. A very low head pressure transducer was mounted on the primary unit and the output from this and the angular position sensor on the pitot tube was directed to the ADC port of the microcomputer via a travelling cable, suspended from an overhead cableway.

The operator could choose to carry out a traverse on one out of 6 available cross-sections and load the appropriate boundary coordinate file into the programme. He would check the pitot tube was de-aired and functioning and calibrate the angular position sensor set-zero (see 4.2 Setting Up). The operator would then position the probe at the start of the traverse and run the programme.At given prompts, the operator would enter various parameters such as spacings between readings and number of readings to average at each position.

Unlike the previous programme, the probe stopped at predetermined settings to take readings. Typically the spacing between readings would be set at about 10mm and the wait time, to allow the pitot static tube reading to reach equilibrium, would be from 15 seconds to 2 minutes depending on the change in flow speed between one position and the next.

The computer would "know" when equilibrium had been reached by using a testing routine incorporating a time delay to check consecutive sets of averaged velocity readings and remain in the 'wait' loop until successive sets of readings were acceptably close in value.

4.4.1 Flow Charts

The operators instructions follow:

1.Set Discharge and Gate

2.De-air pitot static tube and calibrate
Angular Position Sensor using programme ADVAL

3.Choose Cross-Section

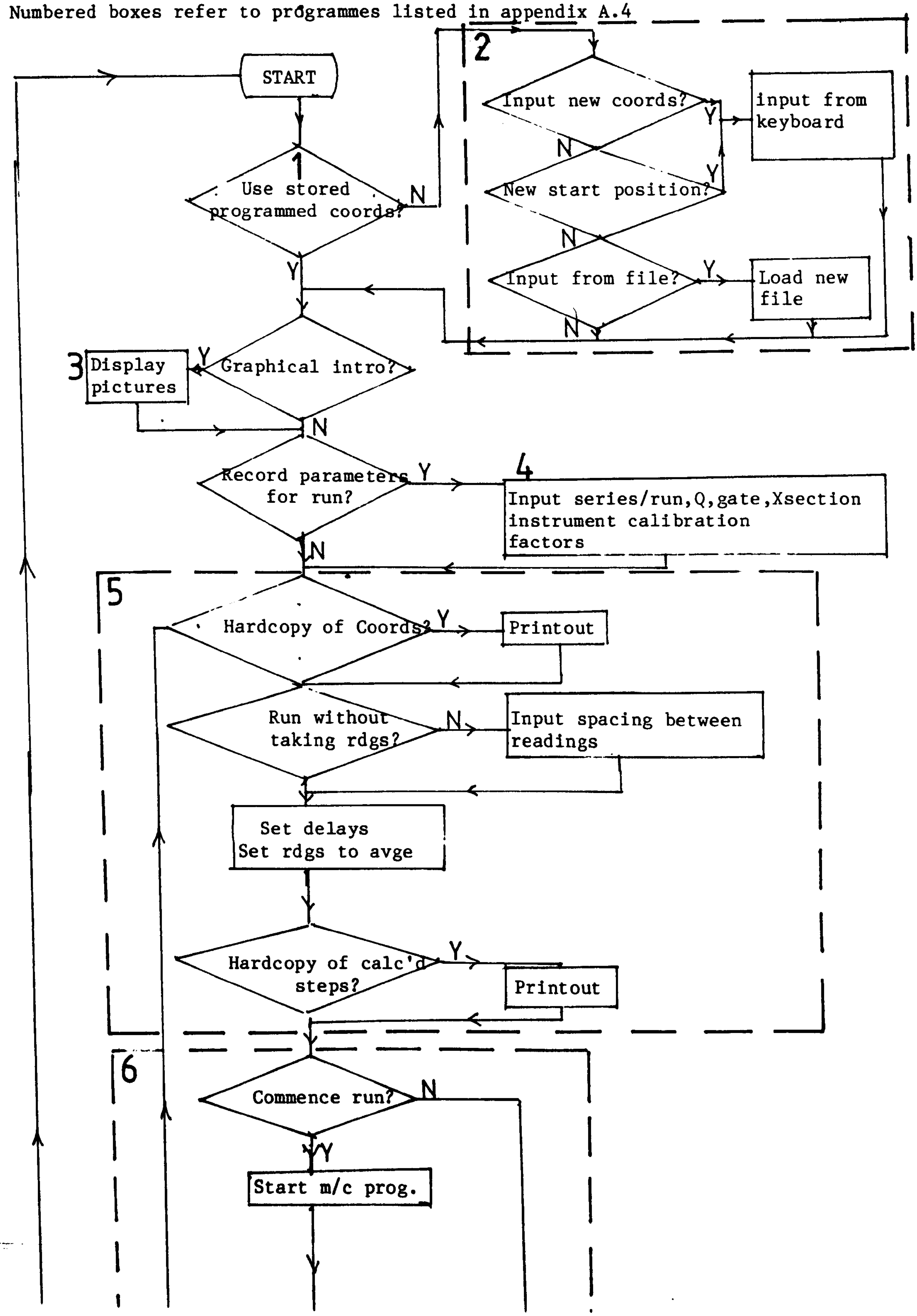
2.Move Probe to Start Position

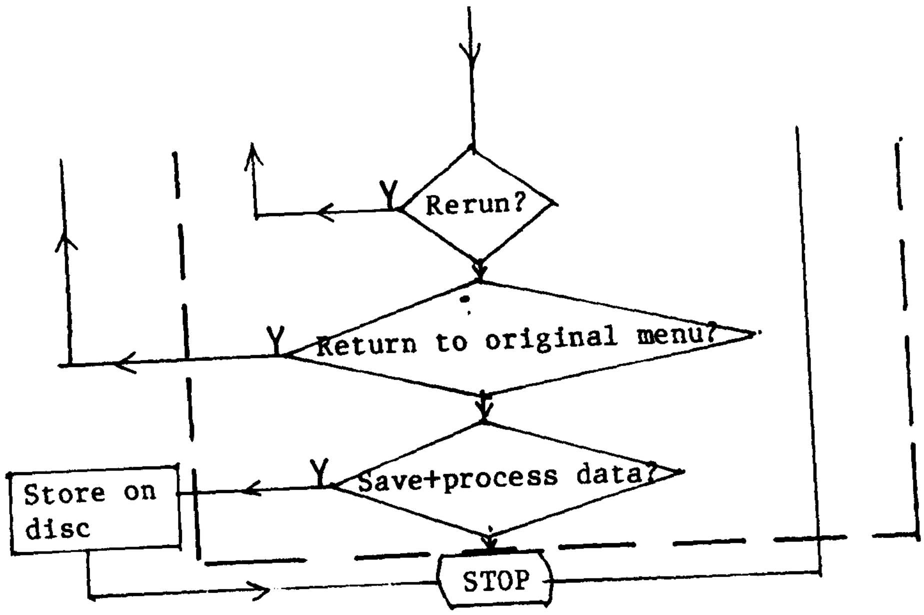
3.Run Programme and follow commands on screen

4.Stop

The running programme consists of a suite of programmes. The following flow diagram outlines the basic sequence and operation of the entire suite. The numbered boxes relate to the programmes in appendix A.4 .

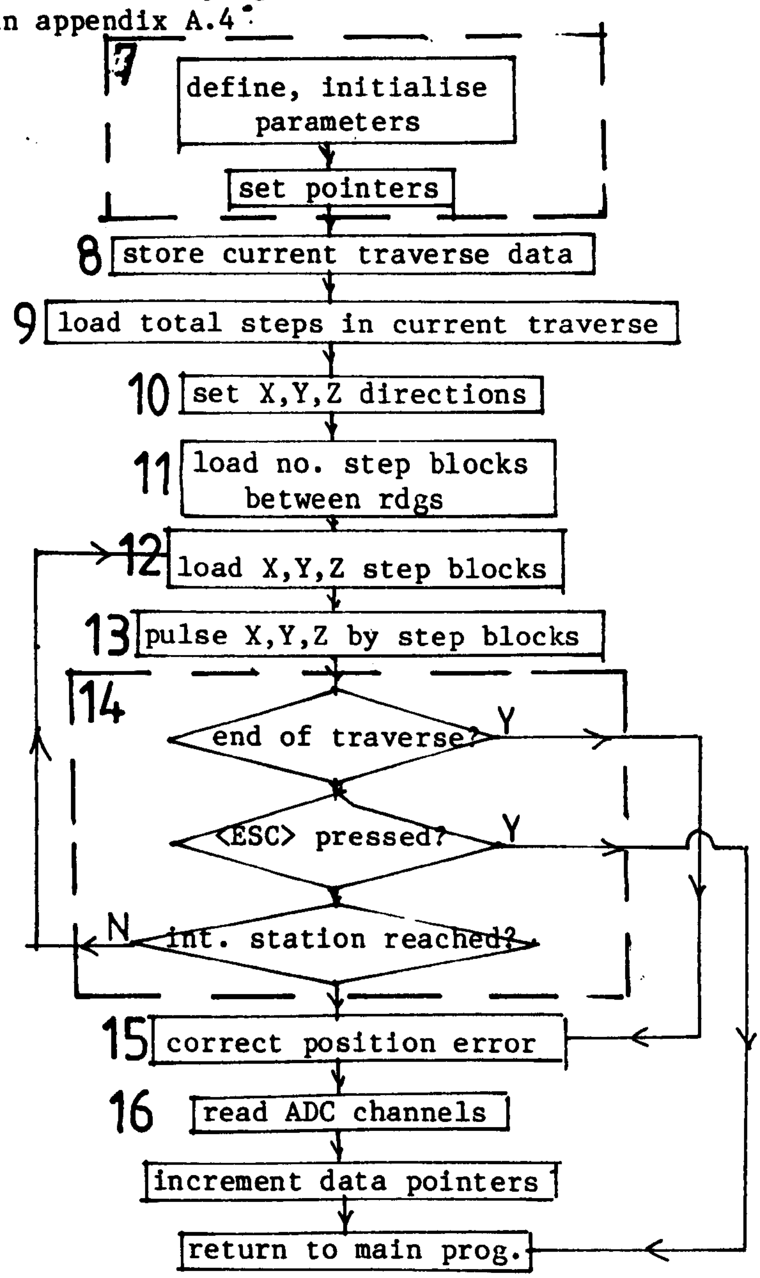
Flow chart for 3D-SUITE of programmes
Numbered boxes refer to programmes listed in appendix A.4





Y
Rerun?
Y
Return to original menu?
Y
Save+process data?
Store on disc
STOP

Flow Diagrams for **3D.ASM**
Numbered boxes refer to programme units within **3D.ASM**
and listed in appendix A.4.



4.5 Isometric Plotting of Water Surface

This third programme has not been as widely used as the first two but its usefulness in future work justifies its inclusion.

The principle of operation is similar to that used for the longitudinal pofiles but instead a number of profiles are taken laterally with a much slower traverse rate and shorter averaging segment. A static water surface level is taken at the beginning of each traverse to tie in successive profiles along the length of the model. The initial level is measured using a pointer gauge with vernier scale accurate to 0.1mm .

A typical isometric plot would be constructed from 20 profiles at 100mm spacings totalling approximately 1000 averaged readings taken at about 10mm spacings.

The data, again stored on floppy disk, could be transferred to a file on the GEC 4090 main frame computer. From there a programme written in Fortran 77 utilising resident plotting packages could produce an isometric view of the water surface. A sample plot is given in Figure 4.2 .

4.5.1 Flow Charts

The operators instructions follow:

1.Set Discharge and Gate
2.Read water level at start position with pointer gauge
3.Position depth probe at start position
4.Run programme and follow instructions on screen
5.Choose new start position and GO TO 2 else STOP

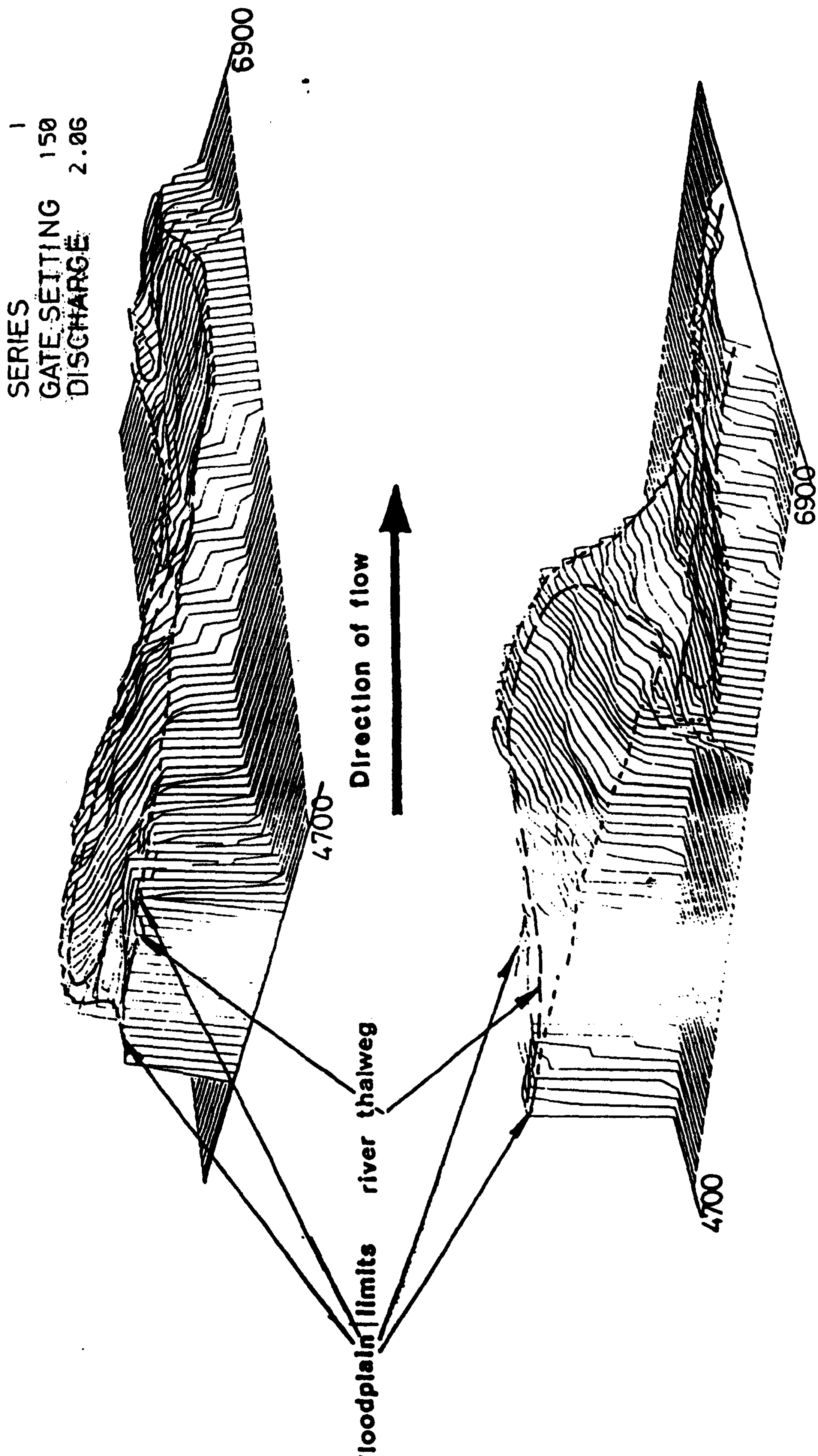


Figure 4.2
Isometric Plot of Water Surface Between Y=4500 and Y=6900

CHAPTER 5

River Roding - Field Measurements and Analysis

As part of the investigation into the 1980 River Roding Flood Alleviation Scheme, a field study was planned to run concurrently with the experimental laboratory work.

The study concentrated on a section of the river altered under the Flood Alleviation Scheme. Thames Water Authority and the University of Bristol decided to site three water level recorders between chainages 300m and 1700m below the village of Abridge, (see figure 1.1 in chapter 1). The stretch of river was comprehensively mapped and figure 5.2 shows the mapped river with the surveyed river cross-sections marked in. The canalised section of the river, immediately downstream of recorder 3, was not typical of a natural compound river about which the investigation hinged and, therefore, monitoring of the experimental scheme was confined to the upper part of the river scheme. Permanent discharge recording stations were in operation on the river at the time.

The aims of the field study were to record levels and infer discharges continuously at the three stations over three years, monitor the type and extent of vegetation in the river and on the floodplain, and whenever possible especially during periods of significant overbank flow, carry out velocity traverses at selected sections along the river.

The results would be analysed to produce a number of stage-discharge relationships for the reach, under different conditions. These would be used to implement a model study of a stretch of the river between sections 1.029 and 1.036. The location and scales of the modelled reach are discussed in chapter 6. Furthermore, the roughness characteristics of the reach would be evaluated to provide design engineers with photographs of the reach together with typical manning roughness values in varying flow and roughness conditions.

5.1 Instrumentation

Figure 5.1 shows the Roding catchment and general location of the wwter level recorder stations and the discharge measurement weirs. Figure 5.2, already introduced, gives in more detail, the position of the recorder stations.

5.1.1 Discharge Measurements

Two permanent weirs specifically constructed to measure discharges in the river are sited near the villages of Loughton and Redbridge, 3km and 11 km downstream of the village of Abridge. Of the two gauging stations at Loughton and Redbridge, the latter station only has been operational since 1983. The upstream station at Loughton, damaged in a storm, was not repaired until 1984. The gauge is currently being recalibrated and has been of no use in assessing discharges along the river during the study.

Water levels over the Redbridge gauging weir are automatically logged at 15 minute intervals throughout the year. The record is processed each month by Thames Water Authority to produce data in the form of a computer printout, listing discharges at fifteen minute intervals beginning at 0900 hours every day on a monthly basis.

Figure 5.3 is a copy of a typical daily record at Redbridge.

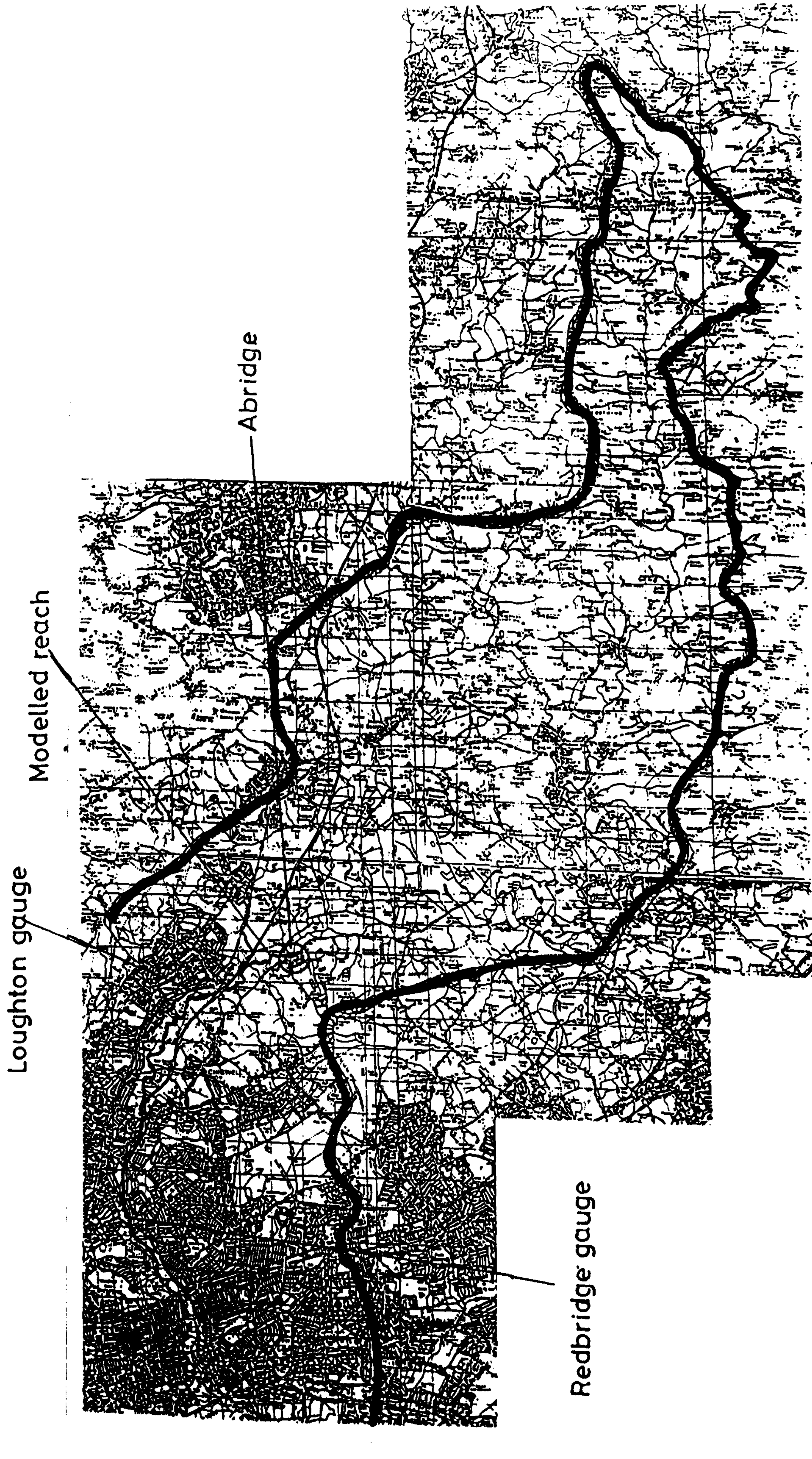


Figure 5.1
Catchment Area of River Roding down to the Redbridge Gauge

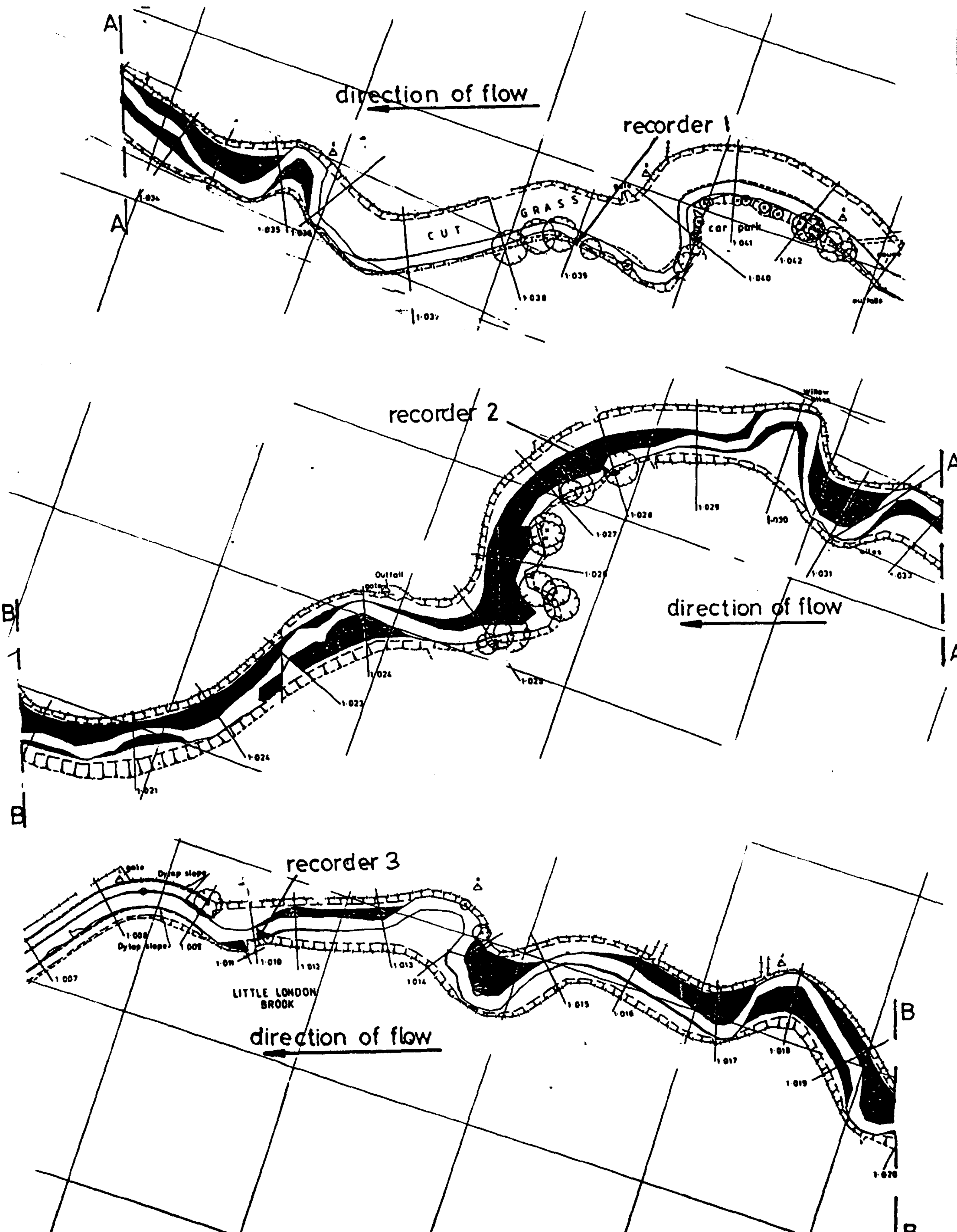


Figure 5.2
Surveyed Plan of River Roding Flood Alleviation Scheme
Between Recorders 1 and 3

THAMES WATER — ENGINEERING DIRECTORATE

CONSERVANCY - LEA GROUP

Punched tape processing for river flows - Daily Summary

RIVER :	RODING	TWA STATION NO. :	56
STATION :	REDBRIDGE	WDU STATION NO. :	37001
DATE/DAY 1 :	01/06/86	CATCHMENT AREA :	303.30 sq.km

Readings are printed at 15 min intervals starting at 0900 gmt on day 1

DAY :- 1 Head above weir crest (Metres)

	.00	.15	.30	.45		.00	.15	.30	.45
09	.279	.278	.278	.278	10	.277	.276	.276	.275
11	.274	.273	.272	.271	12	.269	.267	.266	.264
13	.263	.261	.260	.259	14	.257	.256	.256	.255
15	.255	.255	.255	.255	16	.255	.255	.255	.255
17	.256	.258	.259	260	18	.261	.261	.262	.264
19	.264	.264	.264	.264	20	.264	.264	.264	.264
21	.264	.264	.264	.264	22	.264	.264	.264	.264
23	.264	.264	.264	.263	24	.263	.262	.262	.262
01	.261	.261	.261	.261	02	.261	.261	.261	.261
03	.261	.261	.261	.261	04	.261	.261	.261	.261
05	.261	.261	.261	.261	06	.259	.257	.256	.255
07	.254	.254	.253	.253	08	.253	.252	.252	.251

MEAN = .262 Metres MAX. = .279 Metres MIN. = .251 Metres

DAY :- 1 Discharge (Cumecs)

	.00	.15	.30	.45		.00	.15	.30	.45
09	.975	.968	.968	.968	10	.960	.953	.953	.946
11	.938	.931	.923	.916	12	.902	.887	.880	.866
13	.859	.845	.838	.831	14	.818	.811	.811	.804
15	.804	.804	.804	.804	16	.804	.804	.804	.804
17	.811	.824	.831	.838	18	.845	.845	.852	.866
19	.866	.866	.866	.866	20	.866	.866	.866	.866
21	.866	.866	.866	.866	22	.866	.866	.866	.866
23	.866	.866	.866	.859	24	.859	.852	.852	.852
01	.845	.845	.845	.845	02	.845	.845	.845	.845
03	.845	.845	.845	.845	04	.845	.845	.845	.845
05	.845	.845	.845	.845	06	.831	.818	.811	.804
07	.797	.797	.791	.791	08	.791	.784	.784	.777

MEAN = .853 Cumecs MAX. = .975 Cumecs MIN. = .777 Cumecs

Figure 5.3
Typical Daily Record at the Redbridge Gauge

The first objective of the study was to construct a stage-discharge relationship for the reach, based on information from the three level recorders. One possible method of doing this would have been to gauge the sections containing the level recorders over the investigation period, covering as much of the flow range as possible. This would have proved very costly in manpower and TWA were not prepared to do this.

The only other way of calculating discharges at the sections was to use the permanent gauging stations. An ideal gauging site would have been at the downstream end of the reach, at recorder 3. Failing that, the Loughton gauge would have provided the best alternative. Being out of commission, it was of no use and so this left the Redbridge gauge, almost 8 kilometres downstream of recorder 3.

To assume that the discharge values recorded at the Redbridge site would sufficiently describe the discharges at recorder 3 was unreasonable. A number of brooks and outfalls were situated between recorder 3 and Redbridge as well as surface drainage from a section of the M11 motorway. The additional catchment between the two sites would add to the Redbridge flow in times of rain.

The effect of these inflows would be twofold. Firstly, a substantial increase in short term discharges might be expected, such as that caused by a storm passing over the catchment. This would be due to the rapid runoff from the urban catchment and motorway between the two sites. The second effect would be increased base flow. The first effect could not be accounted for easily, an accurate knowledge of the catchment, outfalls and local rainfall patterns being needed to determine it. The increased base flow between the two locations might be taken into account if the upstream discharge could be measured and compared with the Redbridge discharge for a wide range of flows.

As already mentioned, it was not possible to gauge the river at recorder 3 on a continuous basis, so the only other facility for discharge measurement lay at Loughton, 1.3km farther downstream.

The station at Loughton had been active until 1983 and so it was decided that it might be feasible to use the Redbridge flows and relate them to the Loughton flows, providing reliable correlation could be found between the two. Thames Water Authority supplied the author with 15 minute interval discharge data for both gauges for the first six months of 1982. From this, four periods during which there was significant flow in the river were identified . The data from both stations were digitised and plotted out on a graph of discharge versus real time, to highlight any obvious relationships.

It was apparent that discounting any periods of rapidly varying flow (greater than 0.20 cumecs per hour), two relationships could be developed. Although highly empirical, it was decided that in the absence of any other more accurate information, these relationships would suffice. It was hoped that the validity of these would be checked by comparing the estimated discharge at Loughton, with individual flow gaugings during the study.

A simple translation along both axes was applied to the Loughton data relative to the Redbridge data, which in physical terms equated to the discharge at Redbridge peaking after Loughton and being of greater magnitude. The results are plotted in figures 5.4 to 5.7 . Only Figure 5.4, a plot of consistently high flow, greater than 5 cumecs for over 10 days, showed any reliable correlation.Thus, for flows in excess of 5 cumecs it was decided that a time lag of approximately 3 hours and decrease in discharge of 1 cumec would adequately describe the Loughton flow in terms of the Redbridge gauge. For discharges less than 5 cumecs it was not immediately clear what relationship should apply.

Due to the greater uncertainty in correlating low flows, the author analysed gradually receeding flows of which there are 4 examples marked on figures 5.5, 5.6 and 5.7. These data were replotted, this time relating discharges against each other for different relative time lags.

The best fit set of points was obtained with a time lag of

(Q(loughton))t versus (Q(redbridge))t+3,

(Q(name)) being the discharge recorded on the gauge, t being the time in hours.This has been plotted in Figure 5.8.

The discharge relationship between Loughton and Redbrdige had now been established, albeit fairly crudely. It must be emphasised here that it was a discharge correction that had been established between the two gauges for all steady flows. It was obvious however, that the most important detail was estimating the correct time lag between the Redbridge discharge data and Loughton for each discharge considered. This had already been found to be approximately three hours but would vary depending on the magnitude of flow down the

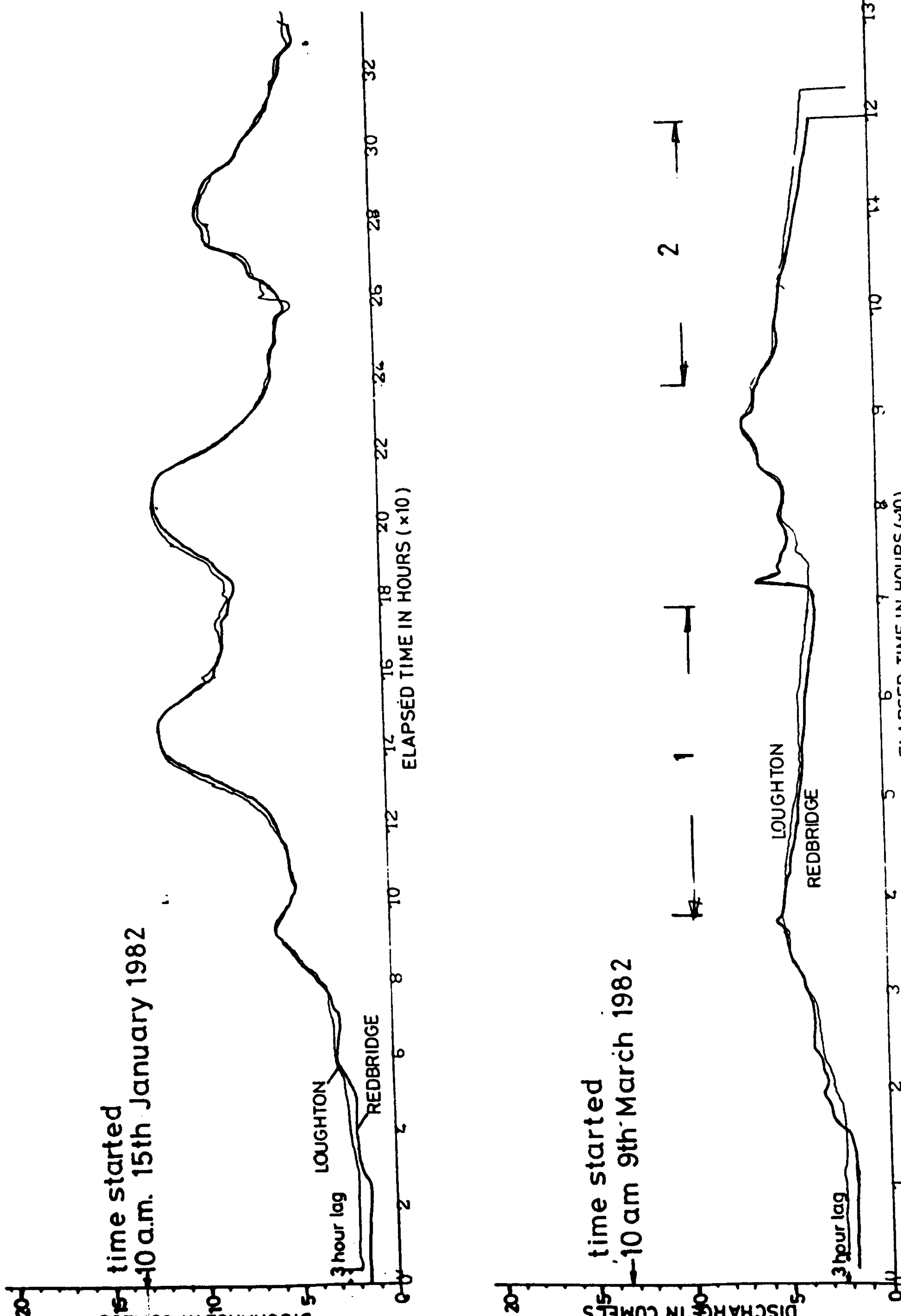


Figure 5.4 and Figure 5.5
Redbridge and Loughton Discharge Data
Loughton Data Plotted with 3hr Lag and Reduced by 1 Cumec
from Original Values to Compare with Redbridge Data

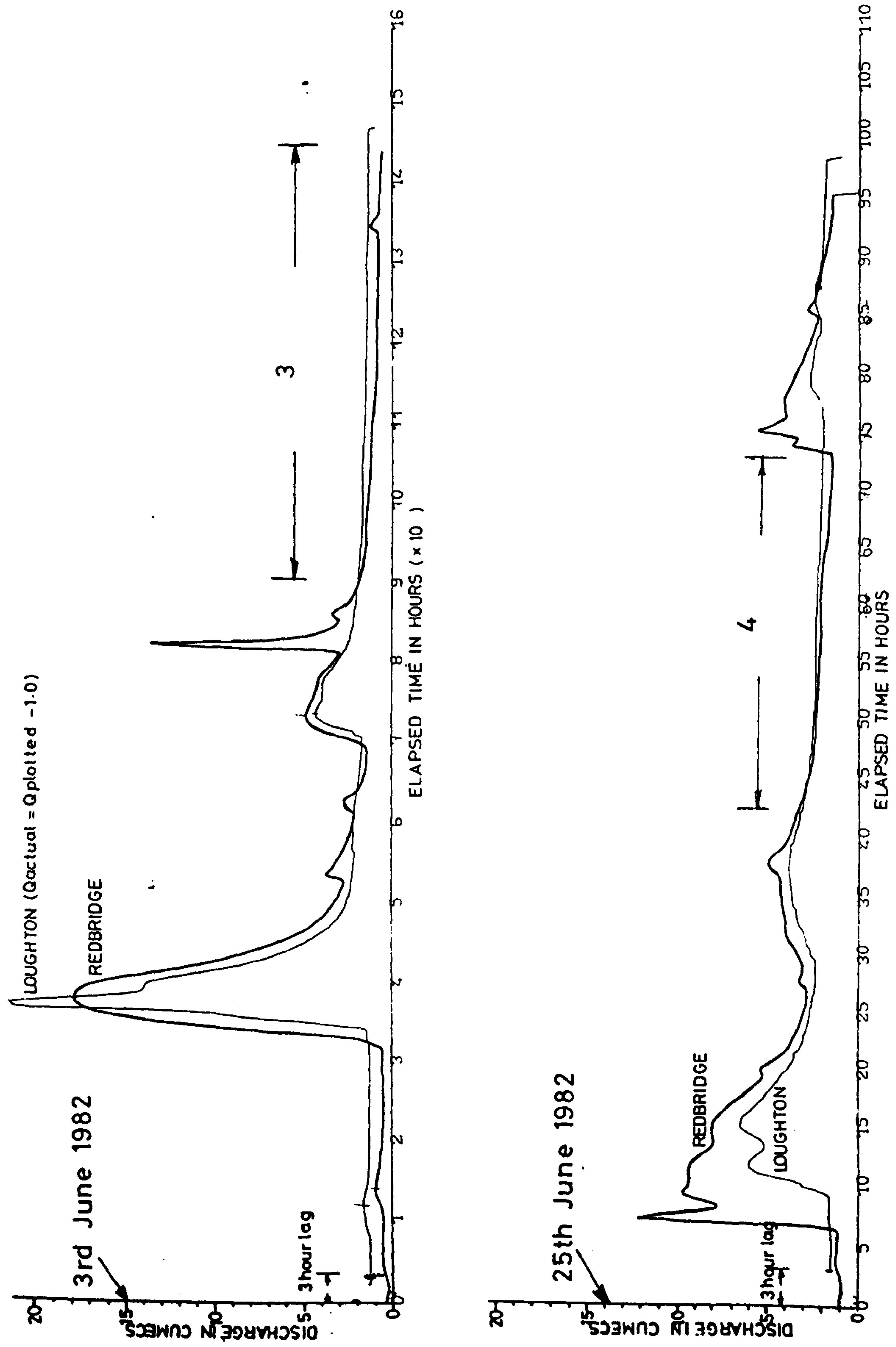


Figure 5.6 and Figure 5.7
Redbridge and Loughton Discharge Data
Loughton Data Plotted with 3hr Lag and Reduced by 1 Cumec
from Original Values to Compare with Redbridge Data

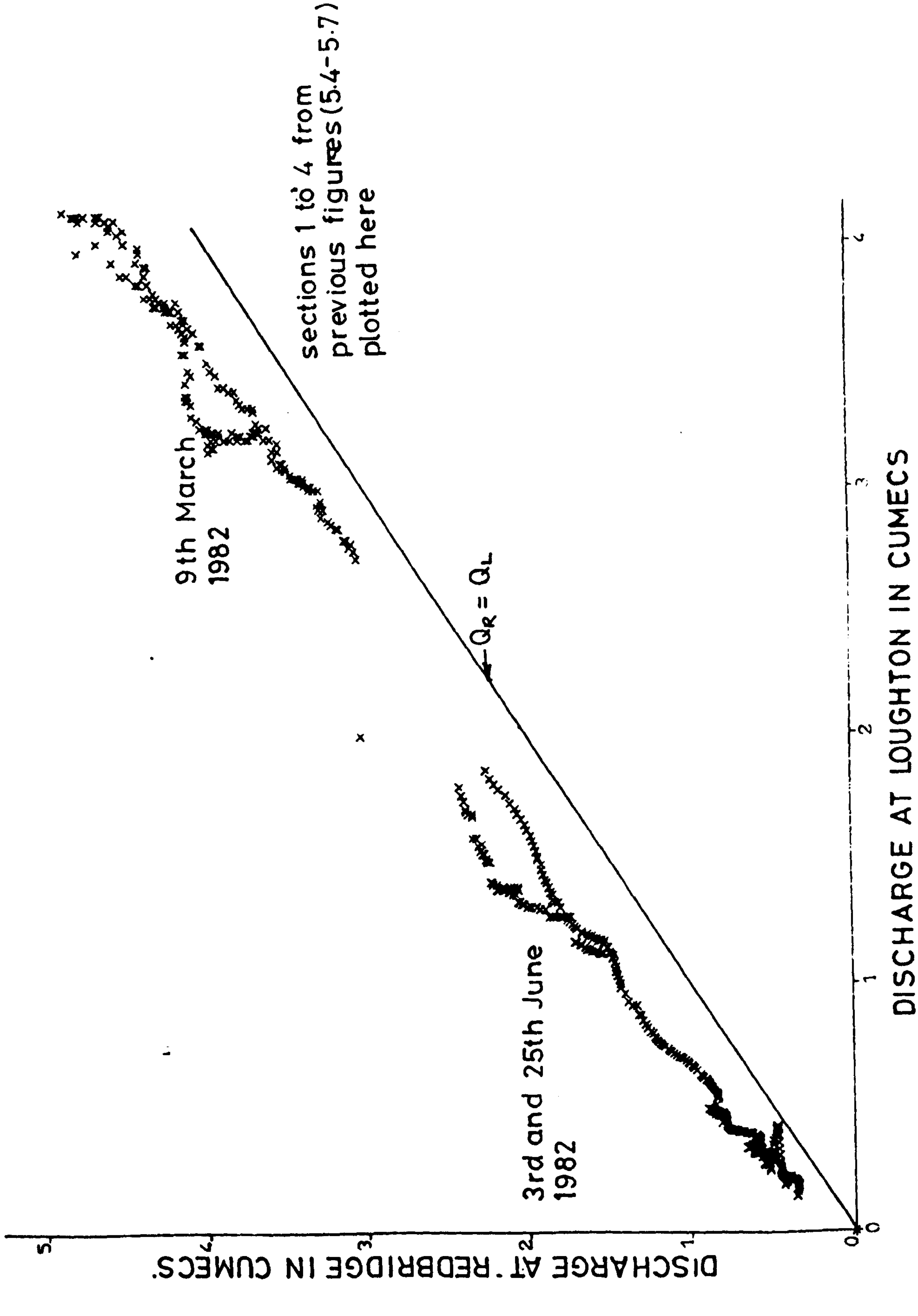


Figure 5.8
Correlated Discharges Between Loughton and Redbridge Low Flows

reach. This was acheived by looking for the characteristic flow pattern at a level recorder station and identifying the same pattern from the printout data of the Redbridge station. That is to say, the peaks, troughs or gentle undulations in the level recorders could be easily recognised on the Redbridge data with an approximate three hour time lag. Therefore, establishing the exact time lag from previous data was not essential. Knowing the discharge difference was more important as the actual time lag could be found by inspection. Figure 5.9 shows a typical chart recording at recorder station 3 together with the discharge values recorded at Redbridge.

It was now possible to estimate the discharge at Loughton. As no further information except manual gauging with a propellor meter at the recorder locations would assist in calculating the discharge further up the reach it was decided that the Loughton discharge would be applied to the whole reach.

The only substantial drainage into the river, upstream of the Loughton gauge and below recorder 3 was from the M11 motorway. The runoff from this would be fairly rapid and as only gradually varying flows have been considered, it was reasoned that this would not affect the estimates of discharge in the reach above recorder 3.

5.1.2 Water Level Measurements

Three Ott Horizontal Water Level recorders were used for the field study. Figure 5.10 includes a block diagram of the recorder layout and a photograph of recorder 1 at section 1.039, just below the village of Abridge.

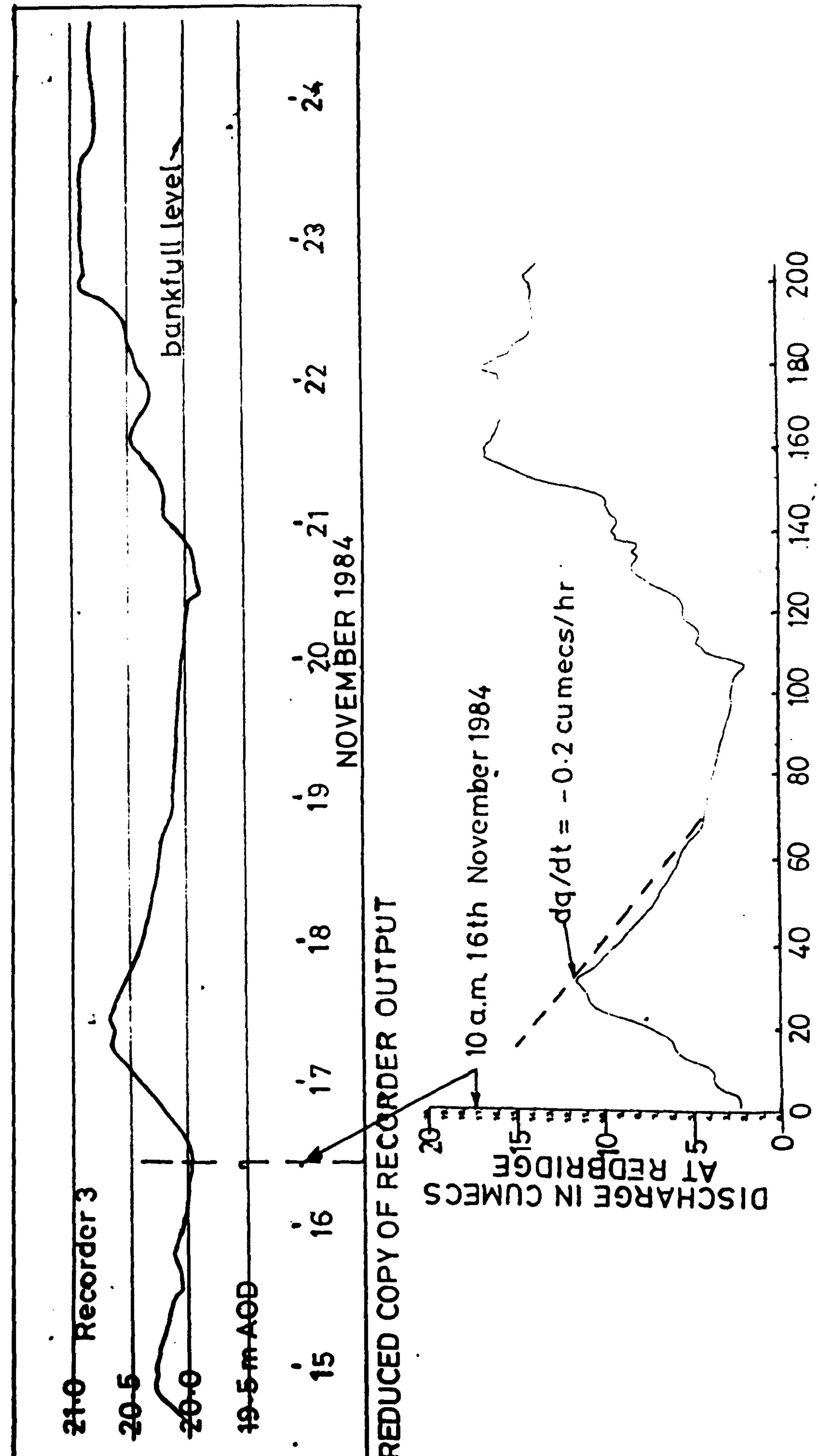


Figure 5.9
Typical Chart Recording at Station 3 with Plot of
Discharge Values Recorded at Abridge

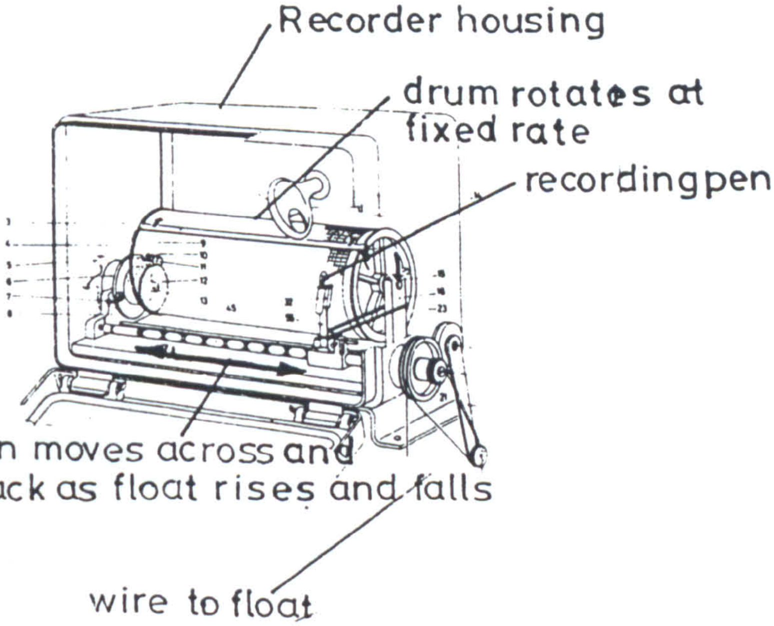


Figure 5.10
Diagram of Level Recorder Layout with a Photograph of Recorder 1

These recorders were installed in the summer of 1983 and not calibrated until the autumn. For the first 9 months, the limits of all three recorders were incorrectly set, leading to a loss of data at times of high flow because the recorders reached their upper limits before the water levels peaked. TWA corrected the problem once it had been picked up but not before all significant flows for the 1983/1984 wet season had been lost. Recorder 1 provided the least information over the three years due to a malfunction of the float at high flows. For the 1985/1986 wet season, recorder 3 failed to record all high flows.

Figure 5.11 is a sample of the output from a recorder chart.

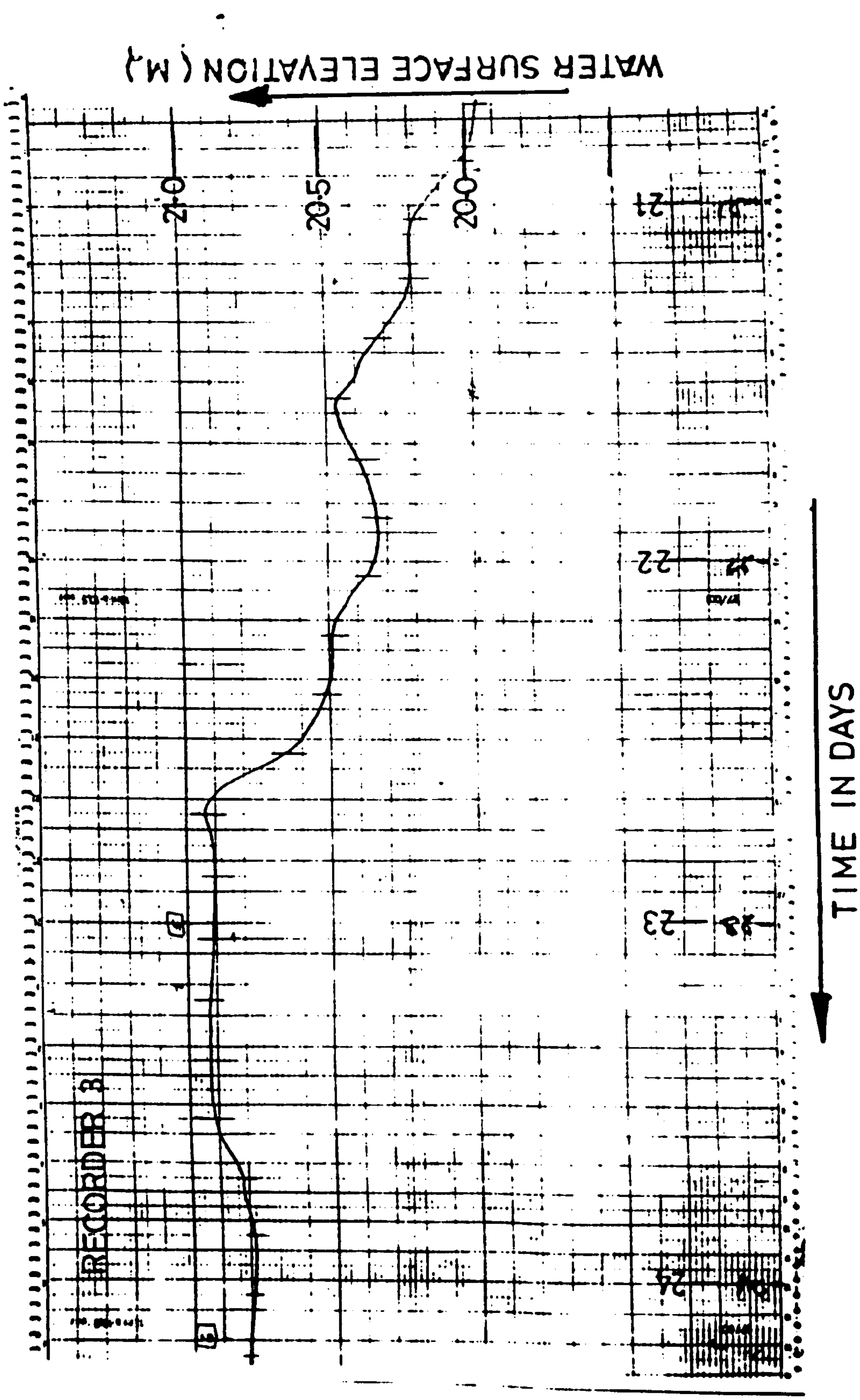


Figure 5.11
Sample Output from Recorder 3

5.2 Vegetation

Dense growths of vegetation on the floodplain are considerd a major factor in the resistance to flow in the river during flooding. TWA, therefore, carry out a costly annual cutting exercise of the floodplain vegetation to improve the carrying capacity of the river during the wet winter months.

One side effect of lowering the banks of the natural river to form the present artificial floodplains in the Experimental Flood Alleviation Scheme was the increased moisture content of the floodplain surface during the summer months. This is due to the natural water table lying closer to the surface of the floodplains. As a result, large quantities and varied types of vegetation abound, encouraged also by surface runoff rich in fertilisers from the surrounding fields.

5.2.1 Vegetation Type and Density

The river vegetation was photographed throughout its seasonal cycle, to record the type and density, in the main channel and floodplain.

Three types of vegetation abounded.

1. Reed growth adjacent to the main channel, up to 2 metres in height, and forming a dense marginal belt up to 2 metres wide. Stems approx. 5-10mm in diameter, very woody.

2. Dense grasses and other marsh plants up to 1 metre in height, broad leaved, thin stems, uniformly covering the floodplain.

3. Aquatic plants in the main channel extending from channel bed to the surface forming, in places, a dense matting difficult to wade through.

Also scattered on the floodplain were small bushes.

Figure 5.12 shows the floodplain vegetation clearly. Taken in mid-June 1984, the vegetation has almost reached its maximum height. Figure 5.13 shows in detail the type of aquatic growth in the main channel..

In June 1984, a short length of the reach was overflown using a light aircraft as low as 300 feet above the ground. A series of photographs were taken from the plane. The door of the single engined two seater Cessna had been removed to enable the author to lean out of the plane during the flight and take near vertical shots of the river, using an automatic SLR camera with power winder. A high level photograph, figure 5.14, taken at aproximately 3000 feet shows the reach between surveyed sections 1.029 to 1.036.

For an analysis of the vegetation, the author pieced together a large scale mosaic of the river between section 1.029 and 1.036. These showed in detail the type and extent of vegetation on the floodplain. The prints were obtained from slides using the Ilford Cibachrome process to maximise the definition. A photograph covering sections 1.029 to 1.032, with lesser detail, is included here, figure 5.15. The aerial photographs were backed up with pictures of the river taken at ground level.

Figure 5.12
Photograph of Floodplain Vegetation (June 1984)

Figure 5.13
Photograph of Weed Growth in Main Channel (June 1984)

Figure 5.14
Aerial Photograph of Modelled Stretch of River (June 1984)
(Sections 1.029 to 1.036)

Figure 5.15
Aerial Photograph of River Roding Between Sections 1.029 and 1.032

5.2.2 Seasonal Durability of Vegetation

Most of the vegetation growth dies off in winter. A combination of weather and overbank flow knocks the vegetation flat with the exception of the more hardy reed stems.

Figures 5.16 and 5.17 show the same bend in March 1984 and November 1984. The bulk of the vegetation in March 1984 had been cleared the previous Autumn but a considerable amount of marginal vegetation remained. The photograph depicting the same bend in November 1984 shows the vegetation beginning to brown and die off. As part of a controlled exercise, no clearing took place in 1984 and considerable stands of vegetation remaining can be seen in the November 1984 photograph.

Bushes and trees lose their leaves during the winter, leaving stiff branches and stems, providing resistance to flow.

Figure 5.16
Photograph of River Bend between Section 1.035 and 1.036
(March 1984)

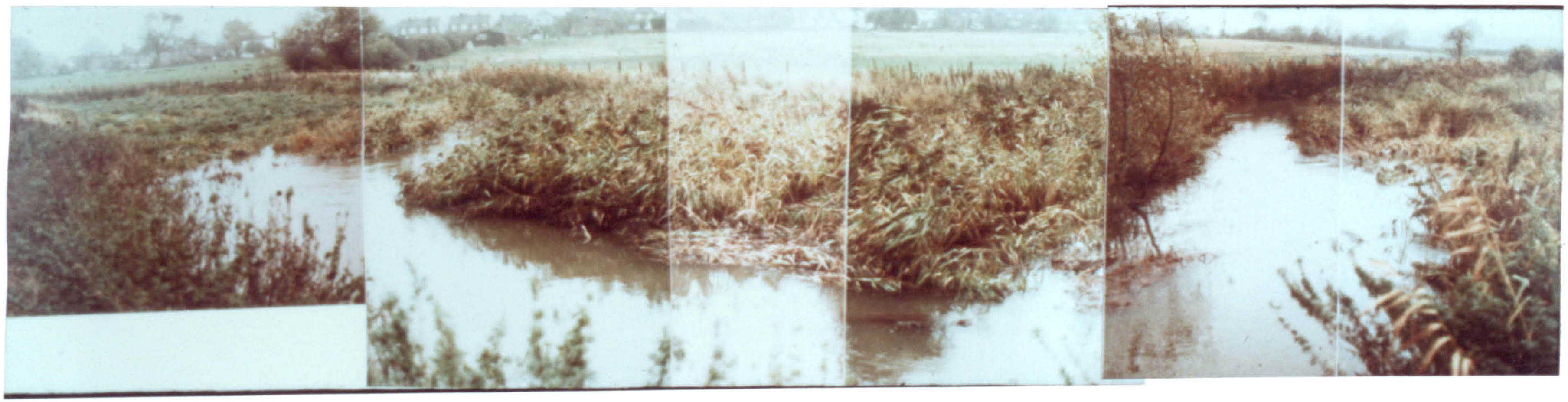


Figure 5.17
Photograph of River Bend between Sections 1.035 and 1.036
(November 1984)

5.3 Current Metering

Between January 1985 and June 1986, Thames Water Authority carried out several current metering exercises. Only one traverse was within the bounds of the level recorder stations. Table 5.1 is the record of the traverse, taken at section 1.031. An OTT propellor current meter was used. Gauging was carried out by wading the floodplain and using a temporary bridge to gauge the main channel. One velocity reading was taken at 0.5 x depth of flow at each station. The depth mean velocity was obtained by multiplying the recorded velocity by a correction factor of 0.96 . Another traverse was taken at the Loughton gauge, also during a period of high flow. Unfortunately they were carried out whilst the rate of change of discharge was greater than 0.2 cumecs per hour and could not be used to corroborate the previously established discharge calibration of the reach with the Redbridge gauge.

CURRENT METER FLOW GAUGING RESULTS

RIVER : RODING AT ABRIDGE
STATION : RIGHT ANGLE FROM TEMP BRIDGE **section 1.031**
GAUGED BY : BRA + SEW BY WADING
DATE : 4.1.86
METER : OTT NO 56568 WITH PROP NO 1-57089
METHOD OF CALCULATION : MEAN SECTION
DEPTH (D) : 0.5 X D (VELOCITIES ADJUSTED BY .96)
ORIGIN : LEFT BANK

	START	FINISH
TIME :	11.22	12.00
STAGE :	0.000	0.000

VERT NO	TAPE DIST M	DEPTH M	REVS PER MIN	VELOCITY M/SEC	MEAN VEL M/SEC	AREA SQ M	DISCHARGE CUMECS
1	.000	1.400	.0	.0000			
					.3338	1.4900	.4973
2	1.000	1.580	123.0	.5216			
					.4704	1.5750	.7410
3	2.000	1.570	108.0	.4586			
					.4120	1.5350	.6324
4	3.000	1.500	94.0	[illegible]			
					.4140	1.5000	.6210
5	4.000	1.500	[illegible]	.4628			
					.4563	1.5000	.6845
6	5.000	1.500	115.0	.4880			
					.4402	1.4400	.6339
7	6.000	1.380	101.0	.4292			
					.4362	1.0150	.4427
8	7.000	.650	113.0	.4796			
					.3144	.5700	.1792
9	8.000	.490	40.0	.1755			
					.2237	.9800	.2192
10	10.000	.490	68.0	.2906			
					.3616	.9700	.3507
11	12.000	.480	109.0	.4620			
					.4704	.8700	.4093
12	14.000	.390	122.0	.5174			
					.5874	.7800	.4581
13	16.000	.390	167.0	.7064			
					.6257	.7700	.4818
14	18.000	.380	141.0	.5972			
					.6035	.8700	.5250
15	20.000	.490	156.0	.6602			
					.5652	.9800	.5539
16	22.000	.490	122.0	.5174			
					.6418	.8700	.5584
17	24.000	.380	194.0	.8198			
					.7991	.8000	.6392
18	26.000	.420	200.0	.8450			
					.8736	.8300	.7251
19	28.000	.410	231.0	.9752			
					.8212	.7000	.5748
20	30.000	.290	174.0	.7358			
					.6096	.2950	.1798
21	31.000	.300	126.0	.5342			
					.3418	.1500	.0512
22	32.000	.000	.0	.0000			

TOTAL DISCHARGE(CUMECS) = 10.1598
TOTAL AREA(SQ M) = 20.49
MEAN VELOCITY(M/SEC) = .4958

Table 5.1
Current Meter Flow Gauging Results at Section 1.031
Carried out on 4th January 1986

5.4 River Erosion

With the abundant growth of vegetation on the floodplain, it is unlikely that it would scour. However, it was worth investigating whether scour channels between clumps of vegetation might be forming. As already mentioned in the introduction to this chapter, a ground survey was carried out in 1983 to map accurately the stretch of river and a number of detailed cross-sections were taken across the river during the exercise. A cross-section survey was carried out again between sections 1.029 and 1.037 in June 1986 to determine whether or not significant changes in level had occurred anywhere on the floodplain or in the river channel bed.Figure 5.18 shows the location of the section traverses in 1983 and 1986. The 1983 traverse location numbers have been marked with an asterisk. An exact reproduction of the traverse lines at each section could not be followed as there were no permanent marker stations at each section. Two permanent ground stations nearby provided the base line for the traverses. Despite this difficulty, the 1986 traverse locations were very accurately relocated and followed fairly closely the 1983 traverses. Thus, a comparison between them could be made. Sections 1.029,1.030 and 1.034 to 1.037 are in appendix A.5 . Sections 1.031 and 1.033 are presented in figure 5.19. Two points worth noting are, firstly, in the inside bend of the main channel, on section 1.033, significant scour has occurred indicating a high

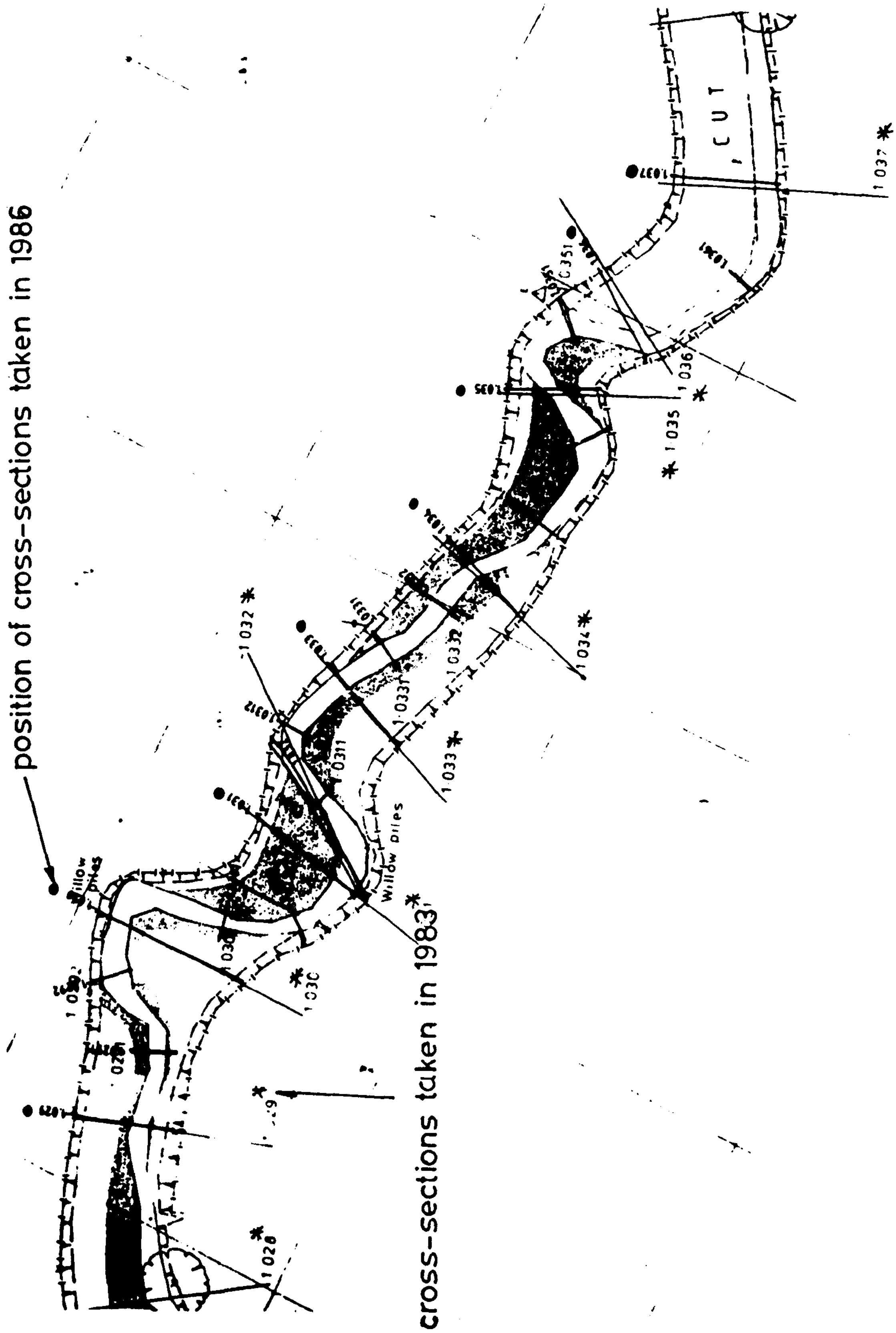


Figure 5.18
Location of Sections of River between 1.029 and 1.036
Surveyed in 1983 and 1986

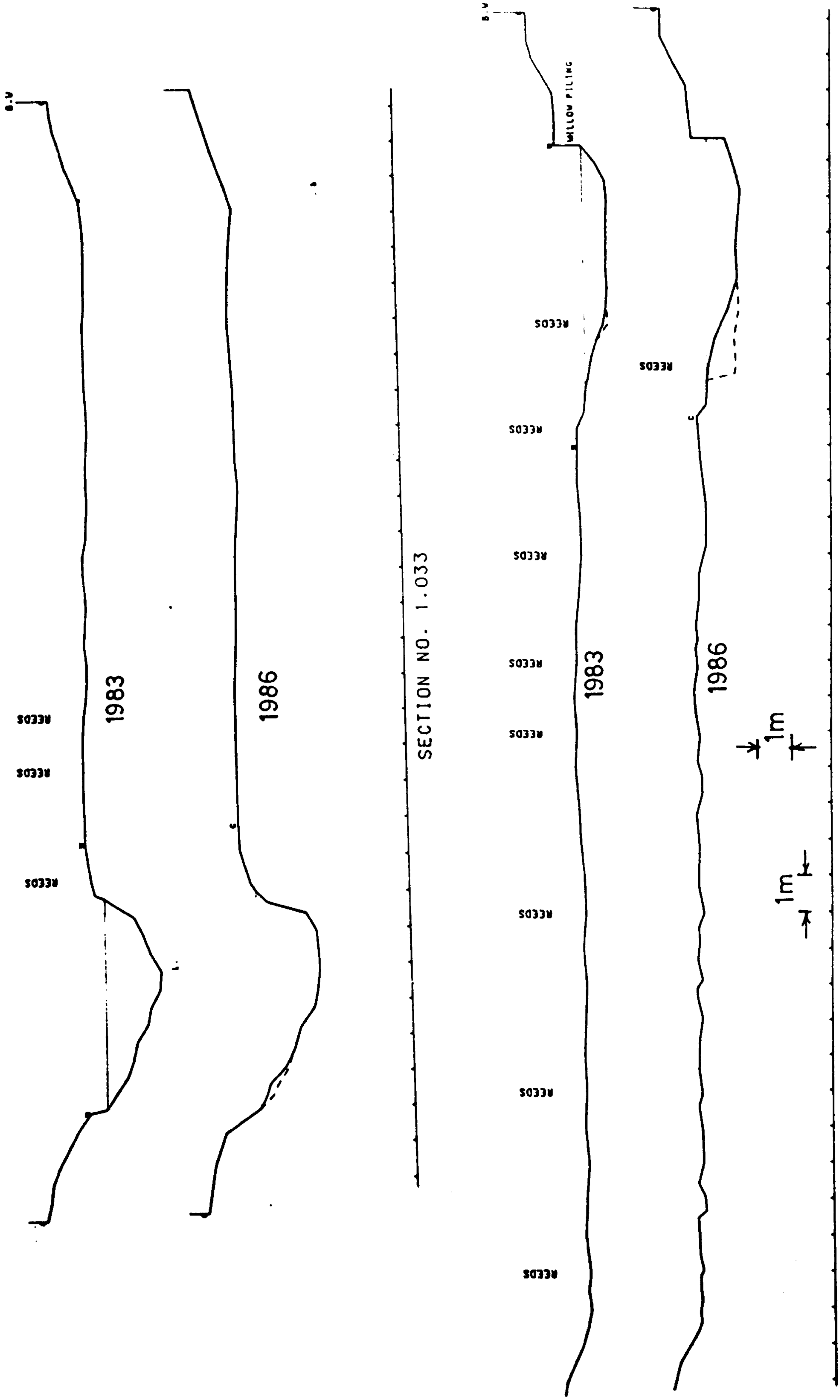


Figure 5.19
Comparisong of Cross-section Surveys of Sections 1.031 and 1.033

velocity gradient there, possibly at times of high flow. On the floodplain in section 1.031, runelling, or longitudinal scour channels appear to have formed, creating an irregular cross-section. A photograph taken in May 1986, of section 1.033, looking upstream towards recorder 1, shows some longitudinal scour of the floodplain with standing water in the low lying areas, figure 5.20.

5.5 Analysis of Field Work

Prototype data is crucial in 'proving' a laboratory model and therefore some of the analysis of the data recorded in the field has been left until chapter 6. In particular, the depth mean velocities recorded at section 1.031 from the velocity traverse.However, stage-discharge curves at the recorder stations are presented here together with associated roughness values calculated from them.

5.5.1 Stage-Discharge Curves

During the 1984/1985 wet season, discharge data greater than 2 cumecs were collected between the last week in November 1984 and the beginning of March 1985. Three lengthy periods of significant flow were recorded from;

16th November 1984 lasting approximately 27 days,

21st January 1985 lasting approximately 10 days and

4th March 1985 lasting approximately 5 days.

A few short duration floods were logged as well. Lower discharges,

Figure 5.20
Photograph of Section 1.033, Looking Upstream towards Recorder 1
(May 1986)

down to about 0.5 cumecs, were much more common in Autumn and Spring and ample points were recorded from October to November 1984 and from April to June of the following year. About 251 discharges were logged during the entire wet season.None of the recorders were fully operational during the period of data collection hence none of the stage discharge curves at the recorder locations were constructed from the maximum no. of data points available. Recorder 1 logged 10 levels out of a maximum 251 recorded discharges, recorder 2 logged 43 and recorder 3 logged 207.

For the 1985/1986 wet season, due to the similarity of water levels at low flows with the previous wet season data, fewer points were recorded for discharges below 10 cumecs. There were also fewer periods of long flow duration for obtaining sets of data points. Data were collected between the middle of December 1985 up to the middle of April 1986. Largest flows were recorded between 10th December 1985 and 6th January 1986. A total of 33 discharges only were logged throughout the season. The peak discharges, however, were much higher in '85/'86 than '84/'85. A much improved recording rate of water levels was obtained, with recorder 1 logging 19 levels out of a maximum 33 recorded discharges, recorder 2 logging 33 and recorder 3 logging 24.

Over the '84/'85 and '85/'86 wet seasons, two controlled experiments were carried out on the river to assess the effect of altering the floodplain roughness on the discharge capacity of the river.

1. In the summer of 1984, the floodplain grasses were left uncut to gauge their effect on the capacity of the river during the winter of 1984/1985.

2. In October 1985, however, the bulk of the grasses were cut on the floodplain with the exception of some marginal vegetation alongside the main channel, comprising tall stands of thick reeds. These were not as accessible being close to the waters edge and therefore in soft mud. As part of the controlled study, it had been intended that all the marginal vegetation be left intact for the 1985/1986 wet season but unfortunately this was not the case. For the analysis then of the discharge characteristics for the river during the 1985/1986 wet season, it has been assumed that normal cutting policy was carried out. That is to say, complete clearance of the floodplain with the exception of some scattered stretches of reeds left intact adjacent to the main channel. In both experiments, the main channel was left untouched and had not been dredged for at least 6 years. It could be assumed, therefore, that the main channel exhibited an established mature roughness state.

The first experiment was to determine the effect of the worst case of river roughness that might occur. The second experiment had been intended to determine the effect of TWA's proposed minimal cutting policy of leaving a fairly wide margin of the more inaccessible reeds adjacent to the main channel. It has still been possible to examine the effect of this policy by use of the laboratory model. Details are included in chapter 7.

The stage discharge curves were constructed from data obtained during the period when the vegetation would have begun to die off. It is noticeable that whereas the flimsier vegetation seemed to die off, the thicker, 'stick' like reeds remained intact during the winter period, thus continuing to provide resistance to flow. Figure 5.21 shows the stage-discharge curves for all three recorders plotted to absolute levels. The loss of data on recorders 1 and 3 can be clearly seen. The recorder sections have been shown in figure 5.22 with water levels just above bankfull included.

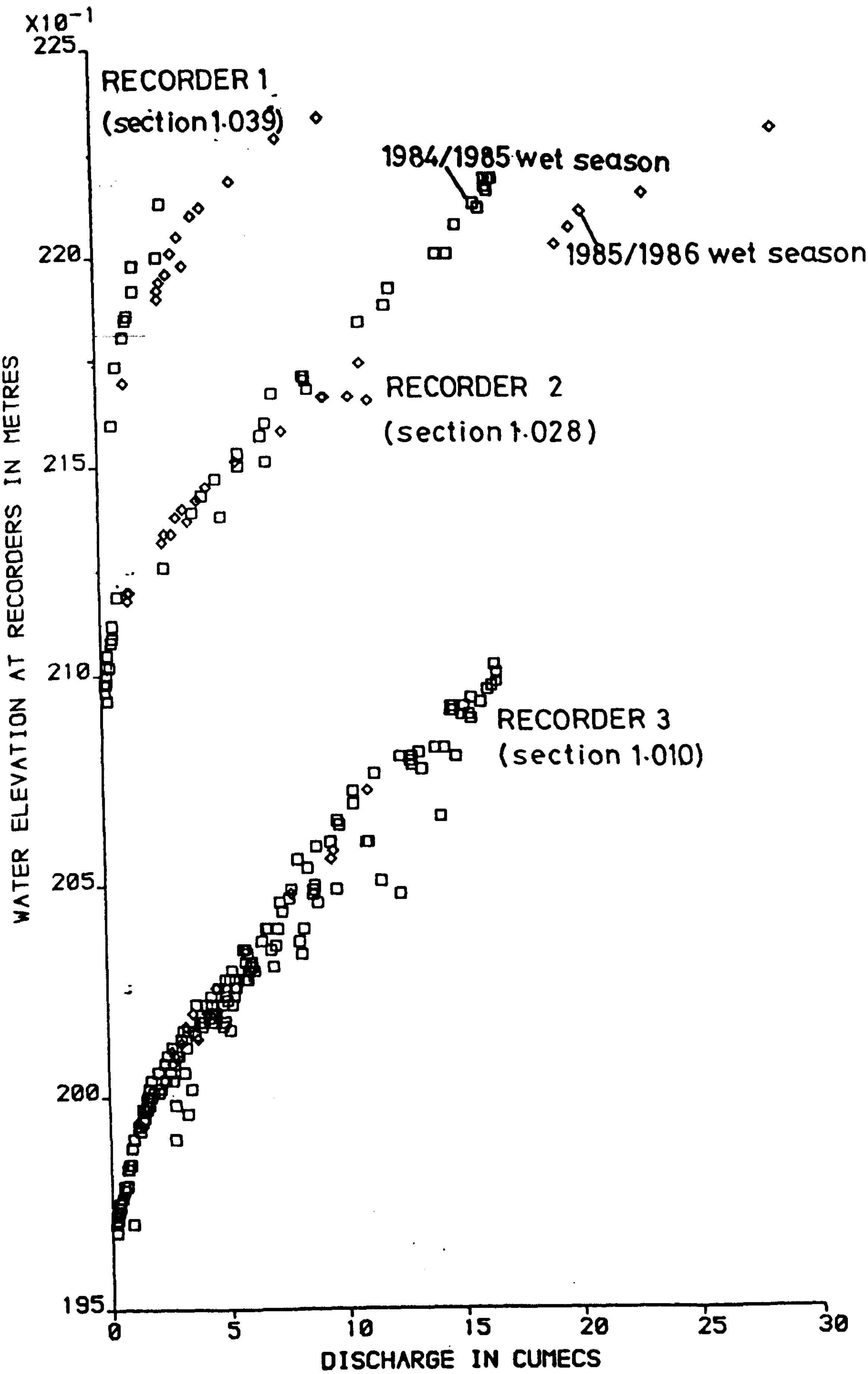


Figure 5.21
Plot of Stage-discharge Data for Recorders 1,2 and 3 for 1984/1985 and 1985/1986 Wet Seasons

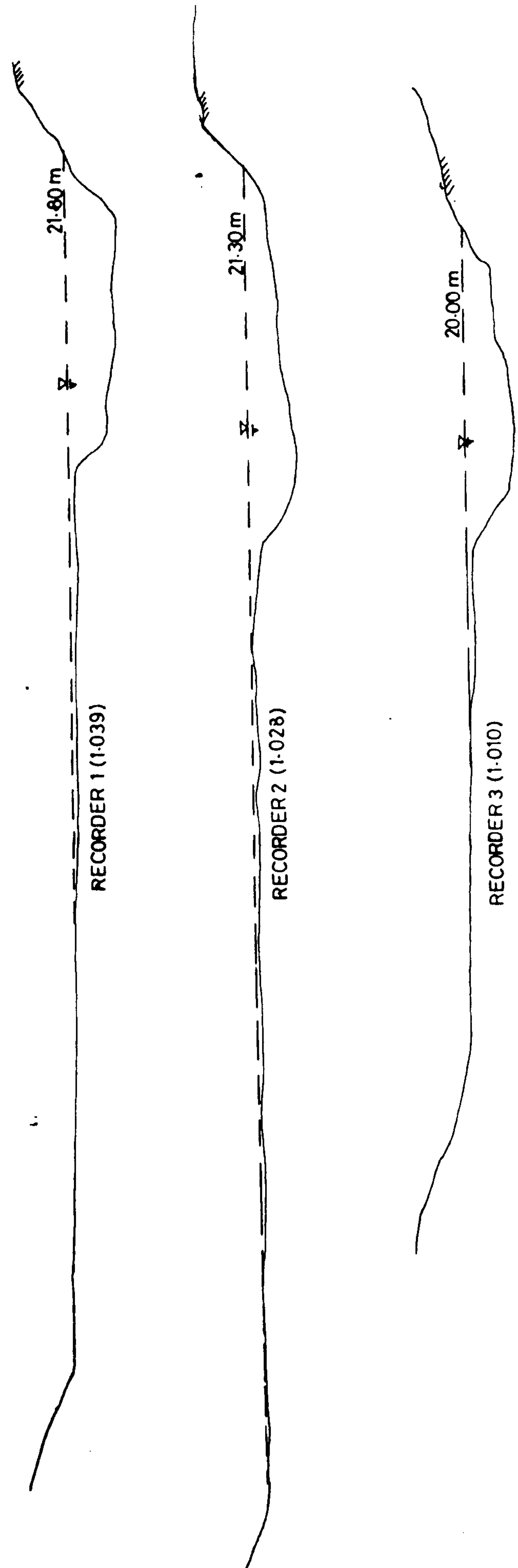


Figure 5.22
River Sections at Recorder Stations 1,2 and 3
Bankfull Levels are Included

5.5.2 Resistance Parameters

Resistance parameters have been calculated for cross-sections 1.010 (recorder 3), 1.028 (recorder 2) and 1.039 (recorder1) for 1984/1985 and 1985/1986 wet seasons. These have been presented in Tables 5.2, 5,3 and 5.4 . They were calculated from tables of discharge, flow cross-section area and wetted perimeter at each cross-section which are included in appendix A.5 .

A mean friction slope of the river when above bank was taken as 1/700, a value obtained from a longitudinal profile of the water surface when uniform overbank conditions obtained between recorder 1 and recorder 3. This confirmed the values used by Wojcik (58) who used a mean floodplain slope of 1/700 and mean main channel bed slope of 1/900 in his design of the Flood Alleviation Scheme. In calculating roughness parameters, and assuming uniform flow, a bed slope of 1/900 was taken for below bankfull discharges. Above bankfull, a bed slope of 1/700 was taken for the entire flow.

Manning 'n' values have been plotted against water elevation for the three recorders, figures 5.23 to 5.25. The 'n' values were calculated by the 'single channel method'. The entire cross-section was used in the calculation of a single 'n' value without subdividing the flow at the main channel/floodplain interface.The single channel method was used to determine the roughness coefficient because none of the cross-sections had a sharp transition from main channel to overbank flow and it was difficult to determine the transition region.

As the depth of flow approached the overbank condition and the river overflowed onto the floodplain , the 'n' value decreased quite sharply. The decrease in calculated roughness just above topbank was to accomodate the rapid decrease in calculated hydraulic radius as the river flooded. James and Brown (15) in their experimental work on prismatic compound channels, calculated 'n' values by this method and produced similar curves where the roughness decreased just overbank and recovered as the depth increased above topbank. However, the decrease in 'n' up to the overbank condition could not be similarly explained. Sargent (65), found that for a number of rivers studied in the U.K , the calculated 'n' value decreased with increasing stage reaching a minimum asymptotic value just below bankfull. As mentioned above, the Roding exhibited the same characteristics below bankfull but without reaching an asymptotic value of 'n'. There is no sharp transition from main channel to floodplain flow due to the irregularity of the river banks and riverside vegetation. Thus, the asymptotic value observed by Sargent near bank full conditions could have been masked by the reduction in 'n' caused by a decrease in hydraulic radius as a result of the transition from in-bank to out-of-bank conditions. In figure 5.24, recorder 2, 'n' value just overbank is considerably smaller than the values at recorders 1 and 3 in a similar state. This could be due to the sharper transition from main channel to overbank flow, causing a greater reduction in 'n' associate with the large reduction in hydraulic radius. Below is a table of bankfull and maximum above-bank 'n' values:

	Bankfull		Above-bank Maximum	
	84/85	85/86	84/85	85/86
Recorder 1	.029	.043	insufficient data	
Recorder 2	.044	.044	.045	.031
Recorder 3	.030	.030	.065	.063

ANALYSIS OF FLOW
Recorder 1
1984/1985

Level (m)	VELY(M/S)	HYD.RAD(M)	RE.NO.	'n'	λ LAMBDA	k (M)
21.50	0.26	0.29	307692	0.063	0.47	0.81
21.75	0.44	0.51	895522	0.055	0.29	0.89
22.00	0.31	0.26	322580	0.049	0.30	0.46

1985/1986

Level (m)	VELY(M/S)	HYD.RAD(M)	RE.NO.	'n'	λ LAMBDA	k (M)
21.50	0.26	0.29	307692	0.063	0.47	0.81
21.75	0.59	0.51	1194029	0.041	0.16	0.44
22.00	0.47	0.26	483870	0.033	0.13	0.16
22.25	0.54	0.45	982456	0.041	0.17	0.42

Table 5.2

ANALYSIS OF FLOW
Recorder 2
1984/1985

Level (m)	VELY(M/S)	HYD.RAD(M)	RE.NO.	'n'	λ LAMBDA	k (M)
21.00	********	********	********	********	********	********
21.10	0.20	0.30	243902	0.086	0.86	1.30
21.20	0.38	0.35	541666	0.050	0.27	0.58
21.30	0.60	0.12	279329	0.015	0.04	0.00
21.40	0.59	0.14	343115	0.018	0.05	0.01
21.50	0.60	0.19	455486	0.021	0.06	0.03
21.60	0.60	0.25	602061	0.025	0.08	0.06
21.70	0.59	0.30	709677	0.029	0.10	0.11
21.80	0.59	0.36	843373	0.033	0.12	0.18
→21.90	0.58	0.42	970178	0.036	0.14	0.27
22.00	0.61	0.47	1146245	0.038	0.14	0.34
22.10	0.59	0.52	1237911	0.041	0.17	0.46
22.20	0.58	0.57	1328273	0.045	0.19	0.59

1985/1986

Level(m)	VELY(M/S)	HYD.RAD(M)	RE.NO.	'n'	λ LAMBDA	k (M)
21.00	********	********	********	********	********	********
21.10	0.20	0.30	243902	0.086	0.86	1.30
21.20	0.38	0.35	541666	0.050	0.27	0.58
21.30	0.60	0.12	279329	0.015	0.04	0.00
21.40	0.59	0.14	343115	0.018	0.05	0.01
21.50	0.68	0.19	521739	0.018	0.05	0.01
21.60	0.70	0.25	701030	0.021	0.06	0.03
21.70	0.75	0.30	911290	0.023	0.06	0.04
21.80	0.78	0.36	1124497	0.024	0.07	0.06
→21.90	0.79	0.42	1312127	0.027	0.07	0.09
22.00	0.79	0.47	1501976	0.029	0.08	0.13
22.10	0.83	0.52	1740812	0.029	0.08	0.15
22.20	0.86	0.57	1958254	0.030	0.09	0.17
22.30	0.87	0.62	2160148	0.031	0.09	0.20

Table 5.3

ANALYIS OF FLOW
Recorder 3
1984/1985

Level (m)	VELY(M/S)	HYD.RAD(M)	RE.NO.	'n'	λ LAMBDA	k (M)
19.70						
19.80	0.28	0.21	229885	0.048	0.30	0.38
19.90	0.46	0.27	509803	0.034	0.14	0.19
20.00	0.37	0.26	382165	0.042	0.22	0.33
20.10	0.51	0.31	625000	0.034	0.13	0.19
20.20	0.51	0.39	808080	0.040	0.17	0.35
20.30	0.49	0.58	1142857	0.054	0.27	0.94
20.40	0.50	0.67	1346153	0.057	0.30	1.19
20.50	0.53	0.72	1524663	0.058	0.29	1.26
20.60	0.54	0.80	1746724	0.060	0.31	1.48
20.70	0.56	0.90	1991341	0.063	0.33	1.76
20.80	0.58	0.96	2216666	0.064	0.33	1.90
20.90	0.60	1.04	2497959	0.065	0.33	2.07

1985/1986

Level (m)	VELY(M/S)	HYD.RAD(M)	RE.NO.	'n'	λ LAMBDA	k (M)
19.70						
19.80	0.28	0.21	229885	0.048	0.30	0.38
19.90	0.46	0.27	509803	0.034	0.14	0.19
20.00	0.37	0.26	382165	0.042	0.22	0.33
20.10	0.51	0.31	625000	0.034	0.13	0.19
20.20	0.51	0.39	808080	0.040	0.17	0.35
20.30	0.49	0.58	1142857	0.054	0.27	0.94
20.40	0.50	0.67	1346153	0.057	0.30	1.19
20.50	0.53	0.72	1524663	0.058	0.29	1.26
20.60	0.54	0.80	1746724	0.060	0.31	1.48
20.70	0.56	0.90	1991341	0.063	0.33	1.76

Table 5.4

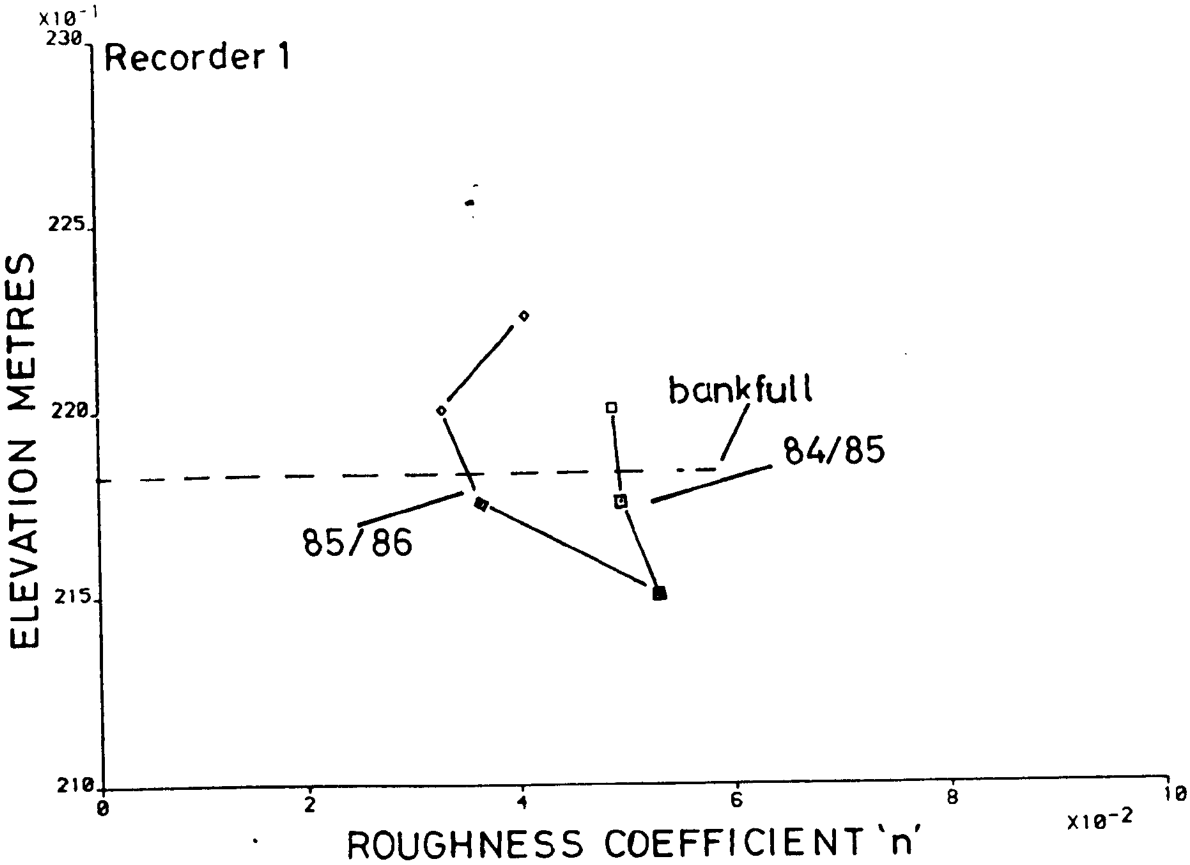


Figure 5.23
Variation of Manning n vs Water Elevation for Recorder 1

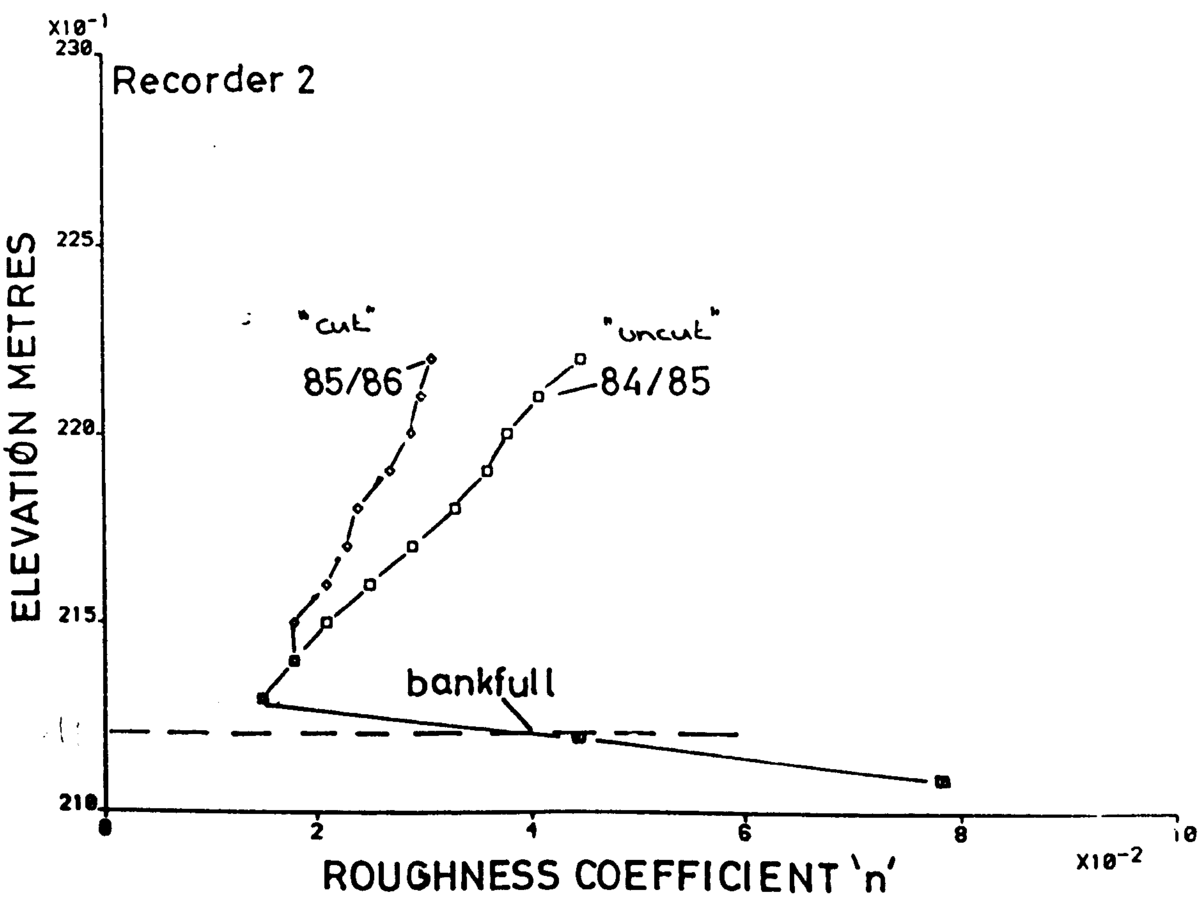


Figure 5.24
Variation of Manning n vs Water Elevation for Recorder 2

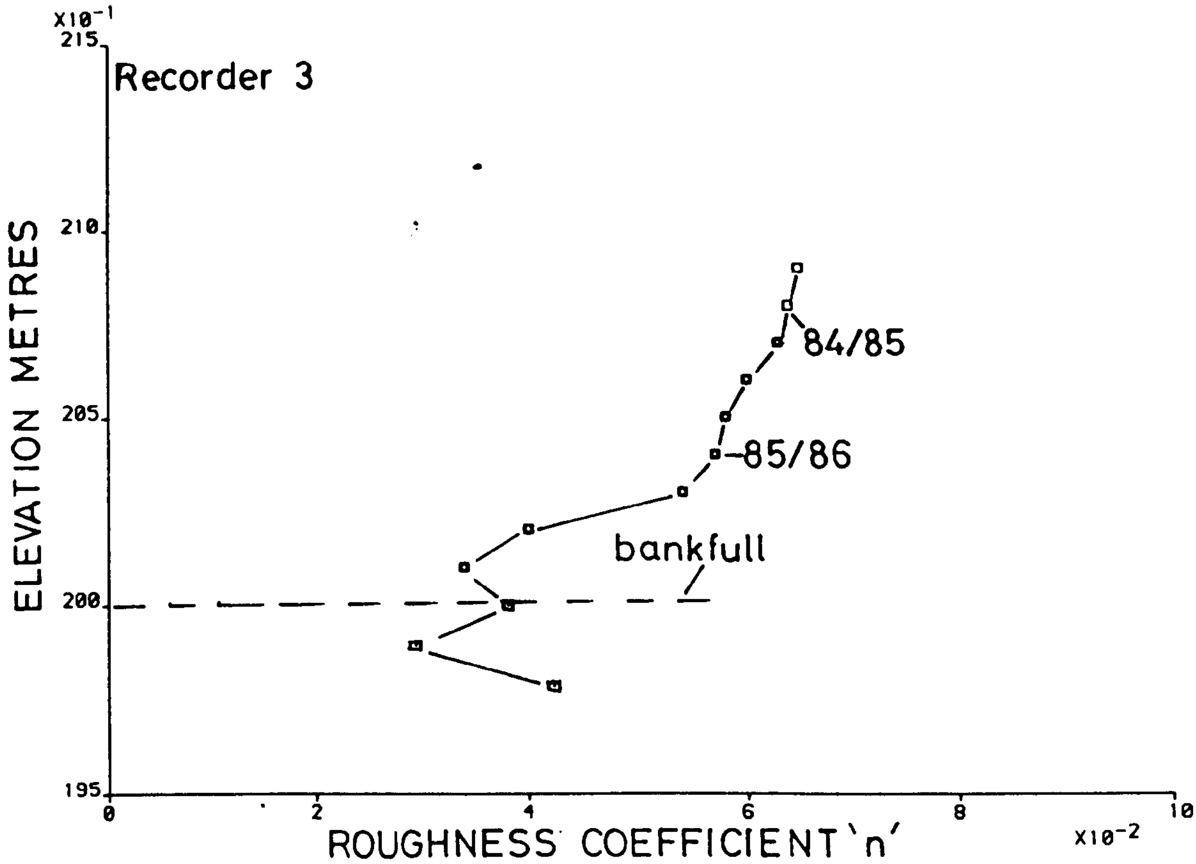


Figure 5.25
Variation of Manning n vs Water Elevation for Recorder 3

Maximum 'n' values at recorder 2 were for flows 1.0m and 1.1m above topbank repectively and recorder 3, 0.9m and 0.7m above topbank.

Recorder 3 showed no variation in above-bank roughness value between the two seasons. This suggests that vegetation cutting does not reduce water levels at this station. Immediately downstream of recorder 3 is a 300 metre straight section of two stage channel. This was built as part of the river diversion works for the M11 Motorway. At first inspection, one would assume the capacity of the artificially excavated canal would have a greater discharge capacity than the natural river. The low 'n' value recorded for bankfull conditions at recorder 3 implies that this might be the case for main channel flow but the high values of 'n' at recorder 3 during flooding could be be due to a backwater effect of the 'constricted' reach downstream. It is possible that the floodplain of the canalised section is not sufficiently wide to match the high flow characteristics of the monitored river upstream. To further emphasise the effect of the downstream reach on recorder 3, the floodplain of the canalised section has never had substantial growths of vegetation on it, unlike the remainder of the river. It is likely, therefore, that the discharge capacity of the artificial compound channel remained unchanged over the two seasons. This could be the only explanation for the similar 'n' values at recorder 3 for the two wet seasons.

Thus, the results from recorder 3 have been discounted in comparing field data to laboratory model studies and as typical roughness values of the river. Recorder 2 has been used for typical 'n' values to match photographs of the river.

A range of 'n' values corresponding to bankfull conditions and topbank conditions for the reach, obtained from the roughness plots, have been included together with photographs of the river in the different states. Figure 5.26, is a photograph of the bankfull condition downstream of section 1.035. This condition corresponds to a roughness value of about .043 . Figures 5.27 and 5.28 show two views depicting floodplain roughness, taken in May 1986. They have a corresponding 'n' value at a submergence of about 1 metre of 'n'=0.031 .

Photographs of flooding between sections 1.029 and 1.036, taken in January 1986, are shown in appendix A.5 .

Figure 5.26

Photograph of Bankfull Flow Downstream of Section 1.035

(May 1986)

Figure 5.27

View of Floodplain looking Downstream from Section 1.034

(May 1986)

Figure 5.28

View of Floodplain looking Upstream from Section 1.034

(May 1986)

CHAPTER 6

Laboratory Modelling of River Roding

A mathematical treatment of turbulent fluid flow with a free surface without considerable simplifications is not possible. In a real situation containing a problem of this nature , the hydraulic engineer can make use of a physical model as a tool for producing technically and economically optimal solutions to specific engineering problems. Thus, a model could be used to convert given input parameters such as geometry, forces, boundary conditions into output parameters such as flow rates and levels.

In the case of the investigation into the River Roding, the reasons for using a laboratory model were twofold.

1. To reproduce in the laboratory, the behaviour of a stretch of the river from known conditions and then experiment on the 'proved' model to predict the effect of altering certain parameters in the field pertaining to a river management programme. The main objectives of the river management programme are to improve the effectiveness of the reach in carrying peak flood flows and to minimise the cost of annual maintenance.

2. To investigate the more fundamental interaction between the main channel of the river and its floodplain. This was of interest because much work had already been carried out on idealised river floodplain geometries but not on the more natural case of which the Roding was a good example.

6.1 Modelling Theory

Research on scale models is based on the theory of similarity between model and prototype. Novak and Cabelka (55) state that the theory of similarity shows:

1. how the model should be theoretically founded;
2. what requirements the model must fulfil to depict reality on a reduced scale as faithfully as possible;
3. which parameters might be measured during an experiment;
4. to what phenomenon the results may be applied and what is the extent of their validity.

Dimensional analysis is the primary approach to determine the criteria of similarity in the investigation of complex trubulent open channel flow.

Two methods of approach are normally discussed in standard textbooks on the subject (55,56) , Rayleigh's method and Buckingham's method. They are well established and will only be mentioned briefly. Rayleigh's method consists essentially of writing down the functional equation which formulates and defines the problem, rewriting the equation in terms of the dimensions in volved and then equating the exponents of [M], [L] and [T] to ensure the equation is dimensionally homogeneous. Buckingham in a more theoretical approach, related the number of parameters in a correct functional equation to the number of variables needed to specify the phenomenon and to the number of dimensions involved.

Two scaling criteria are found to apply to open channel flows. The Reynolds number, $4VR/\nu$, and the Froude number, $V/\sqrt{gd}$, must remain constant between prototype and model to maintain dynamic similarity. R is a typical dimension of length, such as the hydraulic radius of the river, V is the mean flow velocity, ν is the dynamic viscosity of the fluid, g is the acceleration due to gravity and d is the depth of flow.

An inspection of the two numbers will show that the Reynolds number requires VR to remain constant and the Froude number requires $V/\sqrt{d}$ to remain constant, assuming that the same fluid for model and prototype are used and they are subjected to the same gravitational acceleration. Thus, in the case of physical modelling of river flows in an experimental laboratory using water as the fluid, both scaling laws cannot be adhered to.

The Reynolds number is a measure of the importance of the viscous forces and represents the ratio of inertial/viscous forces. The Froude number, however, is a measure of the importance of the gravitational forces and represents the ratio of inertial/gravitational forces.

To model drag effects in rough turbulent flow, it is sufficient to ensure that the model flow is also rough turbulent and the frictional resistance due to form effects is correctly scaled. Sharpe (56), in his textbook

"Hydraulic Modelling", states that the most reliable criteria for determining rough turbulent flow are those in which the Reynolds number is expressed in terms of the shear velocity, V^*, and equivalent roughness size, k, and where

$$V^* k/\nu > 100$$

where the shear velocity is the ratio of the square root of the bed shear stress/fluid density $V^* = \sqrt{\tau/\rho} = \sqrt{(gRS)}$.

This parameter is rarely possible to use as determination of the equivalent roughness size can be very difficult. However, extensive experimentation has shown that above a critical value of Reynolds number, based on mean section flow velocity ,V , and hydraulic radius, R, of about 4000 for open channel flow, the viscous forces acting within the fluid are insignificant in comparison with the inertial forces within the body of fluid.

Invariably, river flow is rough turbulent, with Reynolds numbers in the Roding ranging between 10^5 - 10^6. It remains then to ensure that when modelling the river flows, the model Reynolds numbers are sufficiently high for viscous effects to remain unimportant.

6.2 River Roding Model

6.2.1 Choice of Model Scales

The length of river monitored in the field study was approximately 1.2 kilometres and the average width of floodplain 30 metres, giving a length to width ratio of 40. The laboratory flume, described in detail in chapter 3, was 9.5 metres long and 1.2 metres wide, having a length to width ratio of about 8. To accomodate the entire reach in the flume was impractical as it would have been an uneconomic fit in terms of available area within the flume. The alternative was to model a reduced length of reach, one that would maximise the use of the flume.

It was now necessary to satisfy two criteria, having decided on modelling a fraction of the reach.

1. The reach must contain a meander pattern to allow more detailed experimentation on a natural river meander/floodplain.

2. The reach must be sufficiently representative of the entire stretch under investigation.

To satisfy the second criterion, the proportion of meander to relatively straight section needed to be about the same proportion between modelled reach and entire reach.

A choice of reach was obtained principally by inspection and superimposing the flume boundaries to different scales until a suitable fit was found. A stretch of river approximately 400 metres in length and 300 metres downstream of the village of Abridge was chosen, see figure 1.1 and figure 5.2. This has been reproduced in simplified form with the flume boundaries added and with modifications to the ends of the reach to provide transitions at the inlet and outlet of the flume, figure 6.1 . The proposed 'fit' within the flume required a horizontal reduction in scale of the prototype of 50:1 .

Typical mean velocities and depths on the Roding floodplain during periods of moderate flow, about 10 cumecs, are 0.5 m/s and 0.5 m . Scaled down using a length ratio of 50:1 would give mean model velocities (proportional to $\sqrt{d}$, approximately 7:1) of 70mm/s and 10mm depth of flow. Aside fom the difficulty of measuring such low velocities, the Reynolds number would be sufficiently low for viscous forces to begin to have significant effects within the operating range of the model.

The cross-section of the prototype main channel had an aspect ratio (width/depth) ratio of about 4 . Part of the experimental study was aimed at investigating the more specific phenomenon of the turbulent interaction between a natural river channel and that of its floodplain. Past laboratory research on prismatic compound channels (chapter2), has demonstrated that the interaction phenomenon is maximised for aspect ratios much lower than this.

If the model were to have a distorted scale, to increase the operating flow depths and Reynolds numbers, the following scale ratios for various parameters would apply:

Mx represents the ratio of prototype value(x)/model value(x) where x

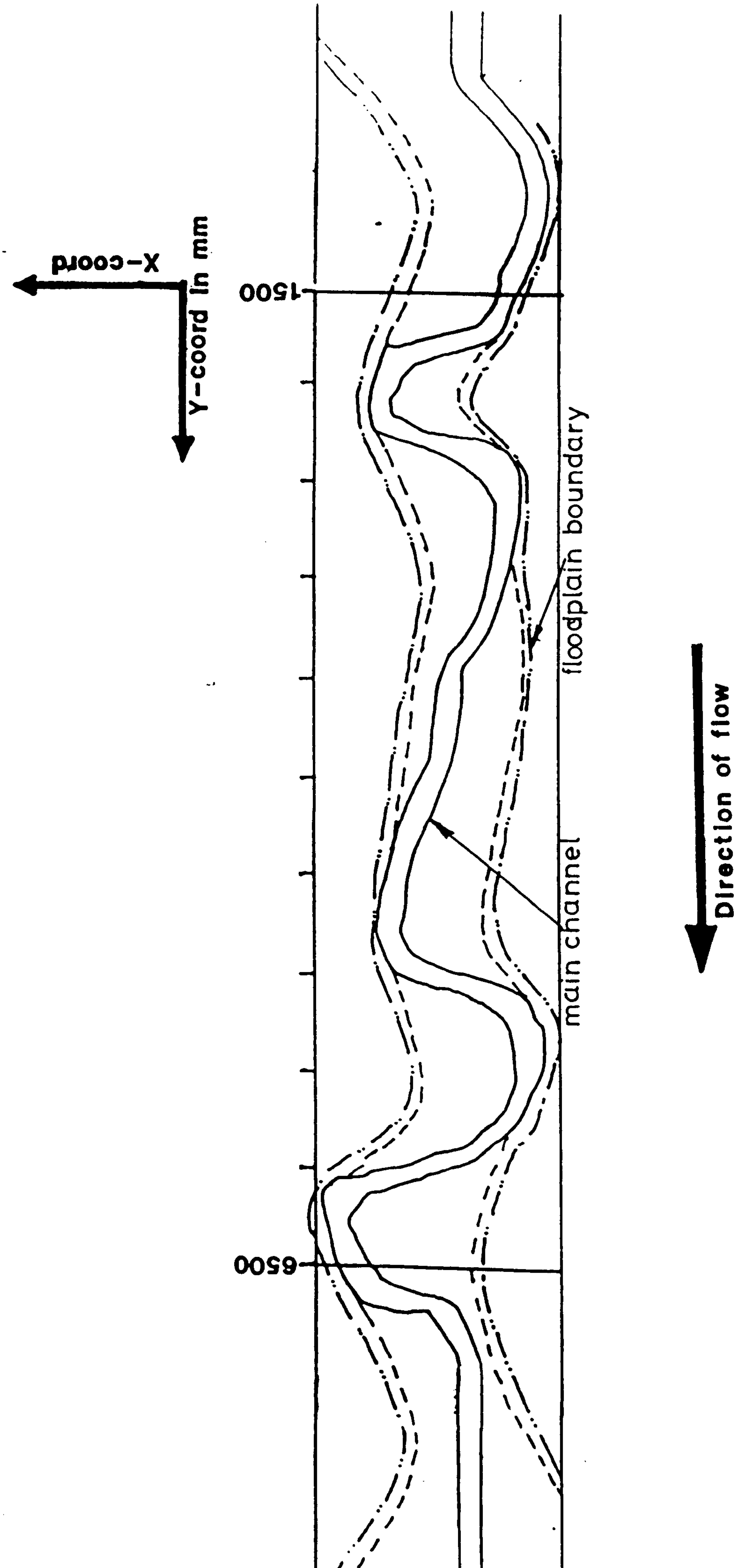


Figure 6.1
Plan of laboratory model of River Roding

is a physical parameter. Given M_d, M_b, M_L, where d is the normal depth of flow, b width of river model and l the length of model

$$M_Q = M_d^{3/2} \cdot M_b \qquad \text{(discharge scale)}$$

$$M_{S_o} = M_{S_e} = M_d/M_L \qquad \text{(bed slope scale)}$$ S_o – bed slope S_e – friction slope

$$M_\lambda = M_{S_o} * M_R/M_d \simeq M_{S_o} \qquad \text{(Friction factor scale from } \lambda = 8gRS/V^2\text{)}$$

Thus, distortion of the model would not only increase the Reynolds numbers on account of the increased flow depth but also the increased bed slope would raise the section velocities over the undistorted model.

Novak has shown that

$$M_R = \Phi\left[M_d, \left(\frac{M_d}{M_b}\right), d\right]$$

where M_R is the scale of hydraulic radius and, therefore, strictly speaking for a distorted model, similarity with the prototype can only be achieved at a single depth of flow. This is because M_R varies with d. However, where the width/depth ratio is large, as is the case for the floodplain which carries the bulk of the flow and R is appproximately equal to d, little variation in M_R will occur and M_R can be equated to M_d.

The calculation below demonstrates the effectiveness of model distortion in increasing the operating Reynolds numbers.

$Re = 4VR/\nu$

$M_{Re} = M_V M_R$ where $M_V = M_d^{1/2}$ and M_R is approximately M_d for a wide channel. Thus,

$M_{Re} = M_d^{3/2}$

For a model with a vertical exaggeration of 3, which is the same as reducing the vertical scaling factor by 3 would increase the Reynolds number over the undistorted case for equivalent prototype conditions by a factor of 5.

One drawback in using a distorted model is the resultant distortion in velocity profiles compared with the prototype , especially at boundary discontinuities such as the main channel-floodplain interface. For large width to depth ratios, such as on the floodplain, comparisons between depth averaged velocities can be made as the flow is largely 2-dimensional.

It was concluded, therefore, that a vertical exaggeraton of the model was a necessary solution. After consideration of the reduced aspect ratio, model Reynolds numbers and the problems of excessive distortion, a vertical model scale of 16:1 was arrived at and the following scale ratios evaluated;

$M_Q = 3200$
$M_V = 4$
$M_\lambda = 16/50$
$M_{S_0} = 16/50$

6.2.2 Construction of the Model

The floodplains of the Roding within the Flood Alleviation Scheme had been artificially excavated and were relatively flat. A slight fall towards the main channel to promote surface drainage had been incorporated but to all intents and purposes, the floodplain could be considered planar with the main channel meandering within it. An aerial photograph showing the modelled stretch is in figure 6.2 , demonstrating the uniformity of the floodplain. Figure 6.3, a picture of the laboratory model without any added roughness, provides a comparison between model and prototype.

The floodplain was constructed as a plane (chapter 3), providing a reference datum for water levels when above the main channel top bank. The floodplain was constructed as an idealised version of the prototype floodplain. Figure 6.4 presents a photograph of the completed model fitted with profile plates of each surveyed cross-section. The 'idealisation' of the floodplain is clearly visible between template and floodplain. The undulations which had been eliminated were to be considered as surface roughness.

In chapter 5, the prototype floodplain bed slope was found to be 1/900. The modelled stretch, however, from the longitudinal survey of the modelled reach had a bed slope closer to 1/1000. Thus, for the model, a prototype bed slope of 1/1000 was adopted.

Figure 6.2
Aerial Photograph of Modelled Reach of River Roding
Shortly after Completion of the Flood Alleviation Scheme (1980)

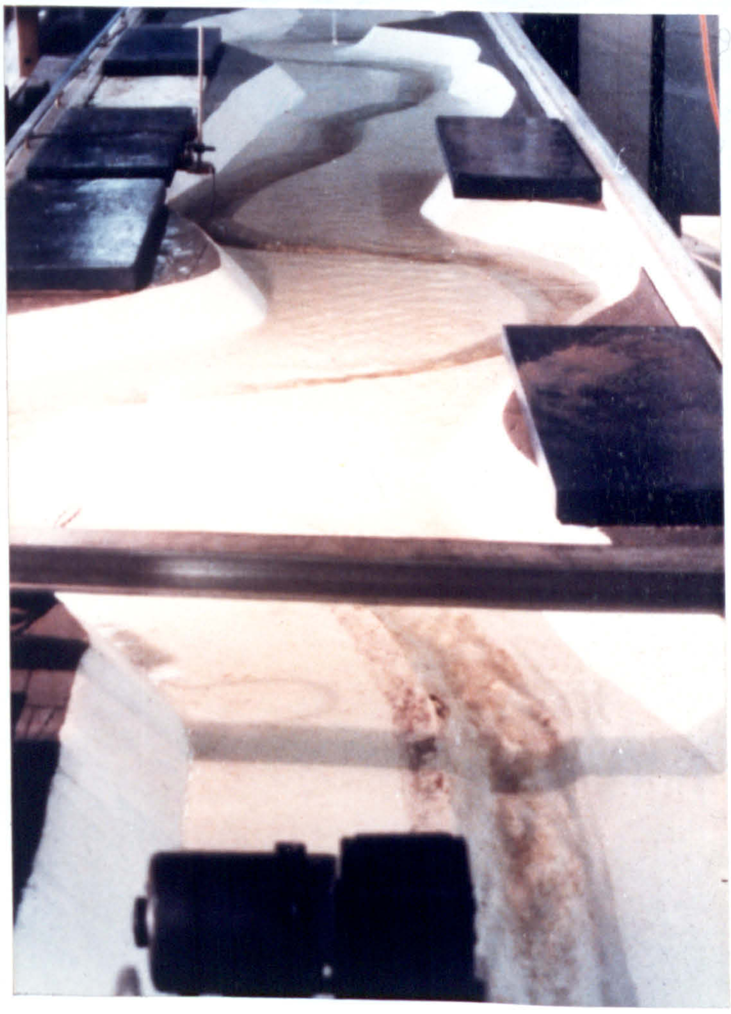


Figure 6.3
Photograph of 'Smooth' Laboratory Model

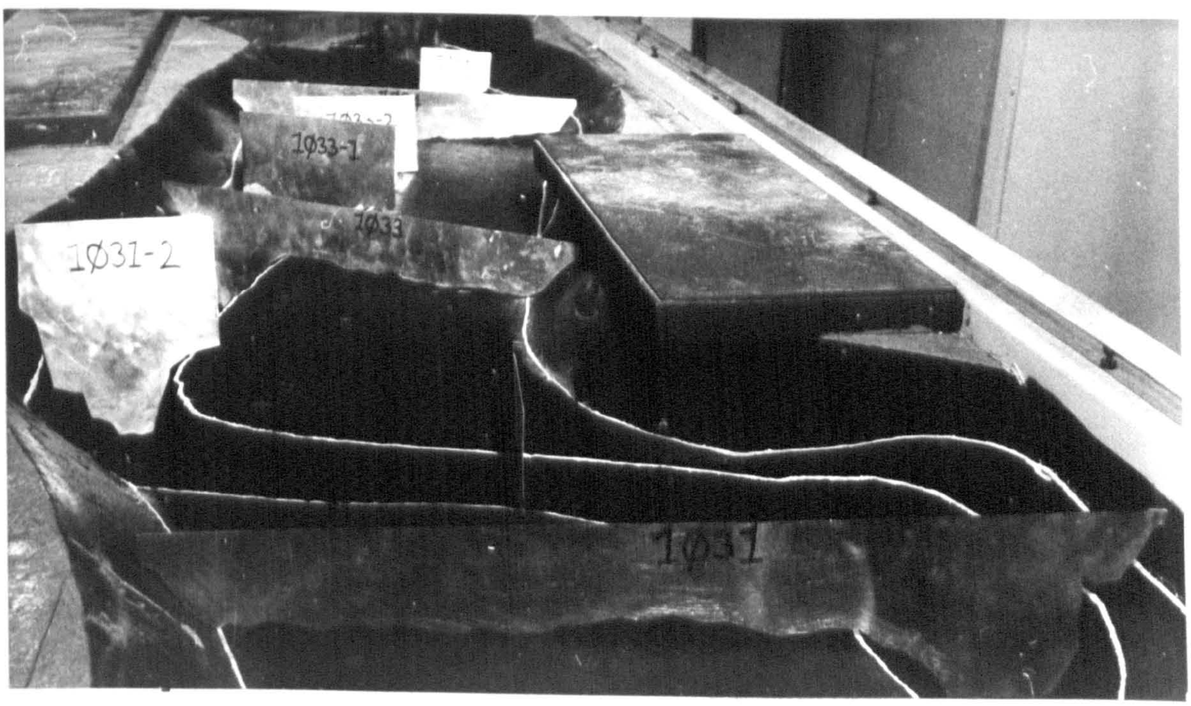


Figure 6.4
Photograph of Model Fitted with Profile Templates

6.2.3 Stage Discharge Curves

The stage-discharge curves were evaluated from a set of normal flow depths for a range of discharges in the model. Almost all of the data were evaluated for overbank flow and the automatic depth logger **(chapters 3 and 4)** could be used down the flume. For overbank flows, the datum for measuring depths of flow was the floodplain. A series of M-profiles, drawdown and backwater curves, were established for a particular discharge by altering the downstream water level using the tail gate. Although the longitudinal profiles were not as smooth as would be obtained in a prismatic model of simple cross-section, the uniform condition could be readily inferred. Figure 6.5 is a plan of the river model with the position of the longitudinal water surface profiles marked in. Appendix A.6 contains series of these curves for different model roughness configurations. Large surface disturbances were caused by the effect of the upstream bend between Y=1500 and Y=2500 Normal depths of flow were evaluated between Y=4000 and Y=6500.

6.2.4 Stage-Discharge Conparisons with Field Data

The field data, presented in chapter 5, have been used in this chapter to provide a comparison with the model. It is relevant, therefore, to present an assessment of the accuracy of the field material. All discharge measurements were recorded at a permanent weir gauging station. The calibration of this weir has been

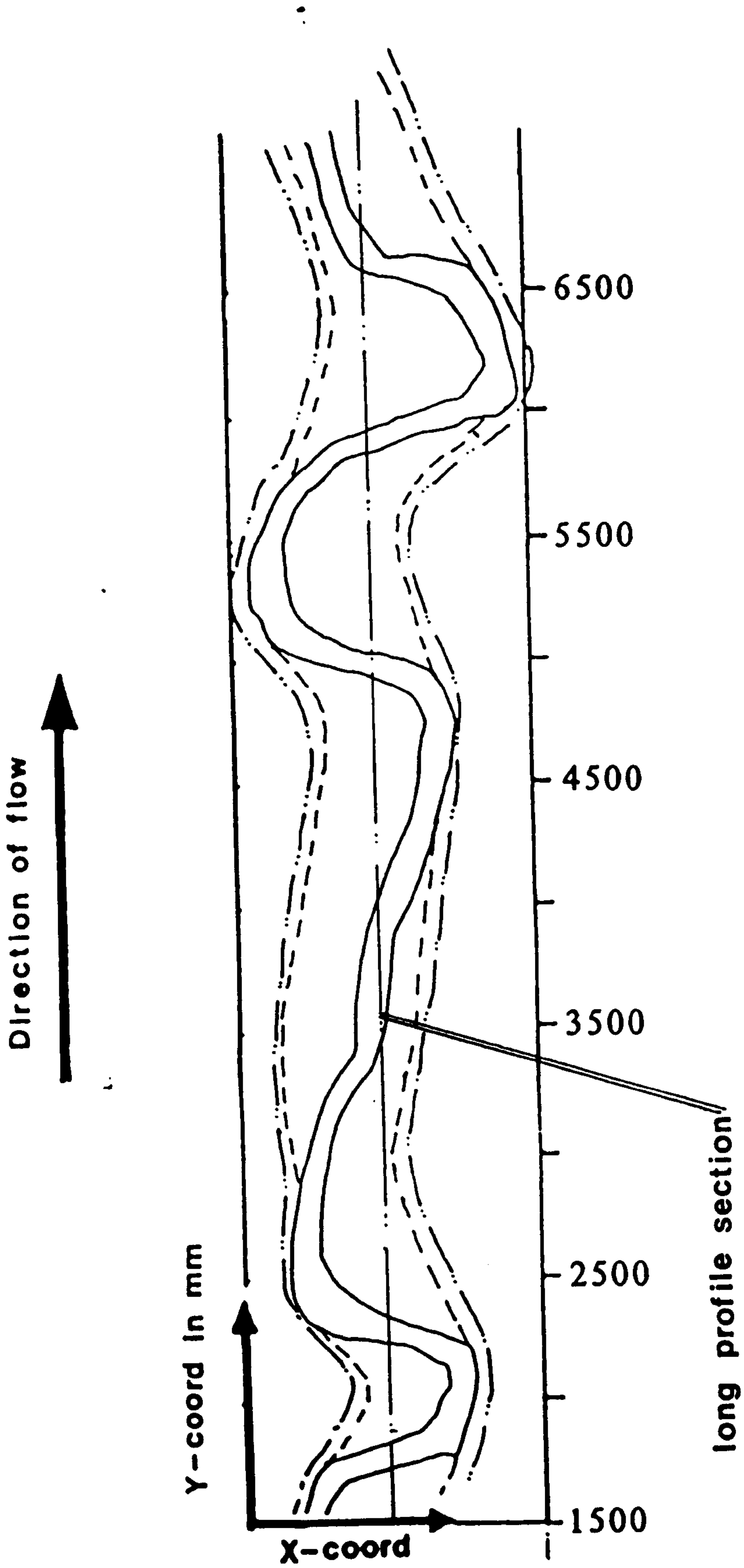


Figure 6.5
Plan of Laboratory Model With Location of
Longitudinal Water Surface Profiles

determined by numerous discharge gaugings of the river using a propellor type velocity meter. From the flow charts, it can be seen that, assuming an accurate calibration, the gauge can be read to within 1% of the correct discharge. However, TWA have stated that the gaugings are accurate to within 5% . To compound the problem, the discharge at the gauging station has had to be related in a farily complicated manner to the monitored reach, almost 10km upstream, containing the three recorders. It seemed reasonable that the corrected discharges used, might be in error by as much as 10%. The level measurements could be measured to within 20mm from the charts.. At an operating level of 1 metre above the floodplain, the resultant error would be 2% . In view of the relatively high accuracy of the level recorders in comparison to the measured discharges, only a discharge error band of 10% has been marked on the field rating curves presented in this chapter.

6.3 Model Roughness

Once the model had been constructed and the data collection apparatus commissioned, a stage discharge curve for the model in its unroughened state was produced. The unroughened floodplain surface was gloss painted polystyrene and the main channel gloss painted cement render. A comparison of the prototype data indicated that the model, as had been expected, required extra roughnening. During the experiments to 'prove' the laboratory model, different roughness types had to be used.

In this section, all the roughness types dealt with in the laboratory study are covered, although some have not been used until chapter 7. A complete list of all the roughness types and configurations is given in Table 6.1 at the end of this chapter.

6.3.1 Flexible Roughness Elements

At the outset, the author intuitively felt that the dense vegetation growth on the floodplain could be effectively modelled by flexible roughness elements, to mimic the real roughness. Much experimental work has been carried out on flexible roughness elements. As a starting point, the author decided to use flexible roughness elements on the floodplain and rigid roughness in the main channel. Two papers on flexible roughness by Kouwen and Unny (60), entitled "Flexible Roughness in Open Channels" and Kouwen and Li (62), entitled "Biomechanics of Vegetative Channel Linings", were referred to. These included detailed experiments with plastic strips of thickness varying from 0.125mm to 0.506mm, a strip width of 5mm , undeflected heights from 100mm to 150mm and roughness elements per square metre ranging from 741 to 5000. All elements were aligned with their broad side facing the flow. The element layouts and results of different series are presented in appendix A.6 .

Wojcik (50), assumed a Manning roughness value for the floodplain of 'n'=0.032 when he calculated the floodbank full discharge capacity for the Experimental Flood Alleviation Scheme. Using the Manning equation to describe the discharge-level characteristics of the river;

$$V = \frac{1}{n} R^{2/3} S_o^{1/2}$$

produces scaling ratios for the 'n' value

$$M_n = M_R^{2/3} M_{S_o}^{1/2} / M_V = M_d^{2/3} M_{S_o}^{1/2} / M_d^{1/2} = M_d^{1/6} M_{S_o}^{1/2}$$

gives

$$M_n = 0.90$$

Thus, typical model 'n' values would nearly equal prototype values. Using the design values taken by Wojcik, mean floodplain velocity of 1.33m/s and hydraulic radius of 1.20m, produces a VR product of about 1.5 . Scaled to a model VR value of about .025 and corresponding 'n' of .032 and a model bed slope of .0033 an estimate of suitable plastic roughness type might be found from Kouwen et al. An inspection of the series showed that all were too rough but a general indication of spacing and roughness size had been obtained.

The author experimented on flexible roughness in a tilting laboratory flume, 0.3 metres wide and 5 metres long. The roughness strips were punched out of sheets of acetate, using a speciallly designed punch, in a regular grid. Two thicknesses of sheet were used, 0.13mm and 0.05mm . The strips were 5mm wide and 37mm in length. Details of the roughness elements and experimental results are given in appendix A.6 .

One set of plastic roughness elements, subsequently named FX1, fitted the preliminary design requirements well and a plot of Manning roughness vs Reynolds number and VR is presented in figure 6.6.

In all, six flexible roughness types, FX1 to FX6, were manufactured during the course of the programme. FX3 to FX6 were produced and introduced into the flume without any prior testing in a separate flume to determine their n-VR characteristics. The following table details the FX series characteristics:

plastic type A - 0.13mm thickness B - 0.05mm thickness

SERIES	MATERIAL TYPE	LENGTH (MM)	DENSITY (STRIPS/M^2)
FX1	A	37	1060
FX3	B	50	970
FX4	B	50	1900
FX5	A	50	890
FX6	A	50	1900

6.3.2 Rigid Roughness

Two types of rigid roughness were used on the floodplain, cylindrical rods and Enkamat matting, type 7200.

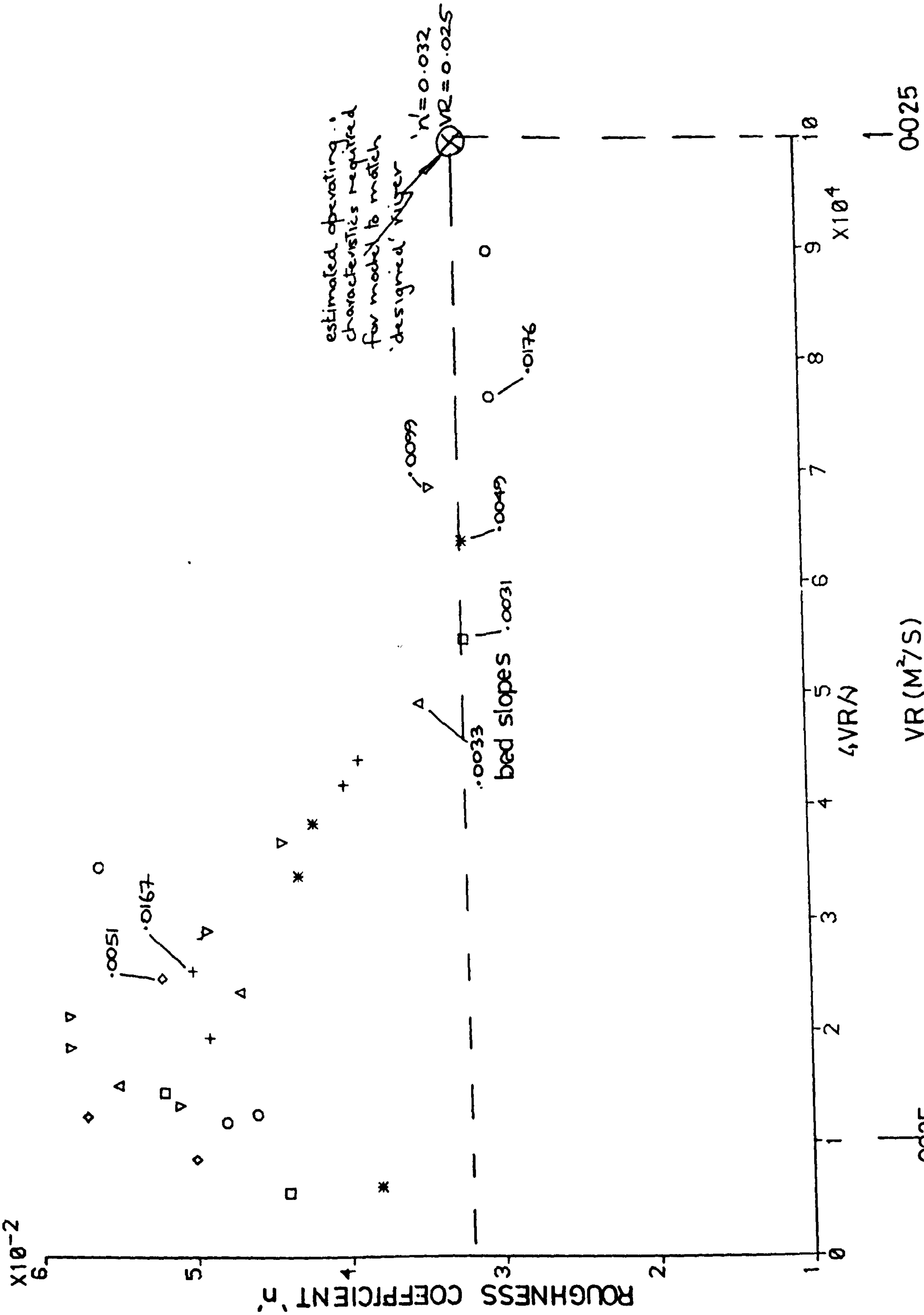


Figure 6.6
Manning Roughness 'n' vs Reynolds Number and VR
for Plastic Strip Roughness FX1

1. **Enkamat Matting**

This material was made of a plastic, formed into a wiry mat with substantial voids between the wires and was approximately 20mm thick. Sheets of the matting were cut and laid out uniformly on the floodplain. They were glued to the painted polystyrene surface with blobs of Arbosil silicone sealant. Figure 6.7 is a photograph of Series 4 with flexible roughness (FX3) mounted on Enkamat matting.

2. **Cylindrical Rods**

Rods of diameter 2.5mm and varying length and separation were used. A photograph of the rods in use is shown in Figure 6.8 depicting the floodplain roughness for series 8 .

Various types of materials were used in the main channel. As the main channel was heavily roughened with weed growth in the prototype, the bulk of material used was to provide near 'clogging' roughness with the exception of series 2 where small angular chippings of mean diameter 10mm were glued to the main channel walls. The 'clogging' roughness used was Enkamat matting,hairlok - a type of dense fibrous matting and 20mm dia. glass spheres.

Figure 6.7
Photograph of Roughness F4 (FX3 ontop of RR2)
Series 5

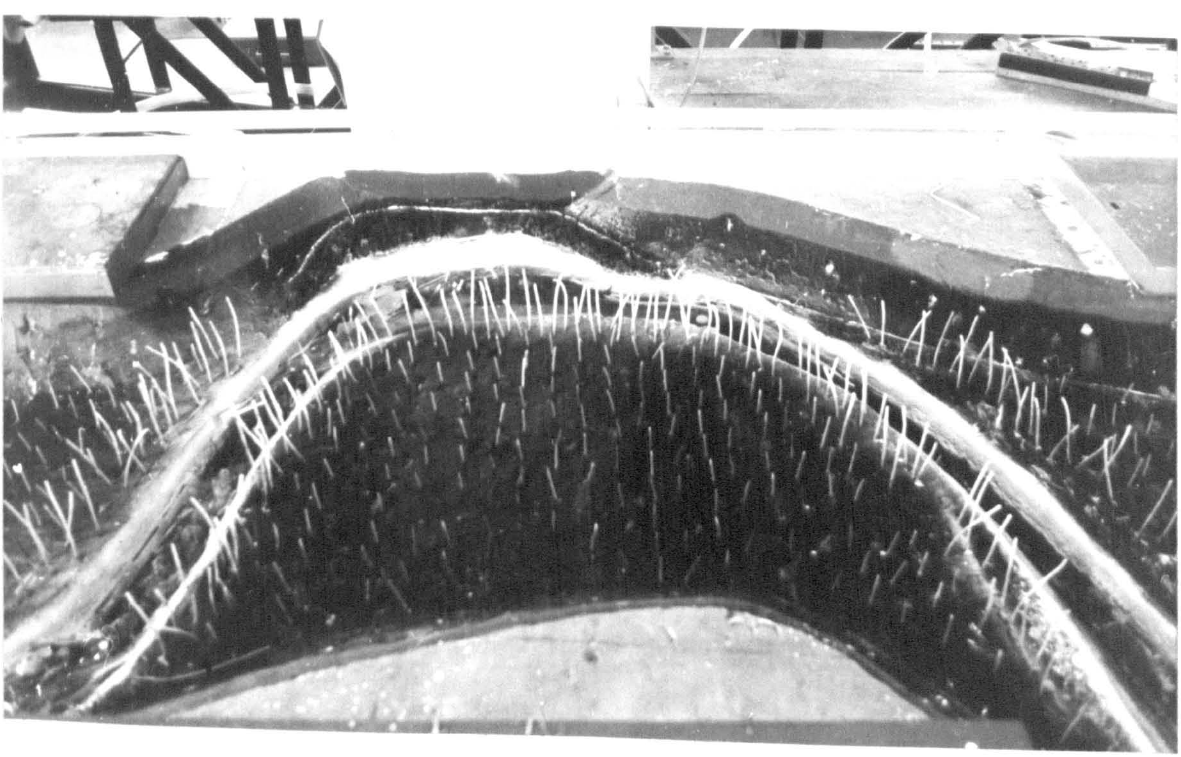


Figure 6.8
Photograph of Roughness F17 (Various RR3)
Series 8

6.4 Proving the Laboratory Model

River data for two wet seasons had been analysed, **(chapter 5)**, and stage discharge curves for the reach between recorders 1 and 3 constructed. Reproducing the behaviour of the prototype in the model from known prototype data, otherwise known as 'proving' the model, was necessary before any constructive experimentation could be carried out.

6.4.1 Preliminary Roughening

The first step in proving the model was to verify whether the selected roughness type was sufficient. For Series 2 of the rating curve experiments, Series 1 being the unroughened case, flexible roughness elements (FX1) were used on the floodplain and pebbles glued to the main channel wall in a regular pattern (RR2). Series 3 employed the same floodplain roughness but the main channel being much too smooth, was filled with hairlok or more appropriately named, 'clogging' roughness. Figure 6.7 is a photograph of 'clogging' roughness.

Depth-discharge curves from recorder 2 for 1984/1985 and 1985/1986 wet seasons have been plotted, with flow depths relative to the floodplain, in figure 6.9 . Bankfull depth was inferred from the intercept of the two slopes of the stage-discharge curve. Recorder 2 has been used as the prototype comparison with the model because the widest range of data had been obtained on recorder 2, it was closest to the modelled reach and recorder 1 upstream, had yielded very little data. Doubt has been cast on the relevance of recorder 3 to the monitored reach, on account of it being sited so close to a very

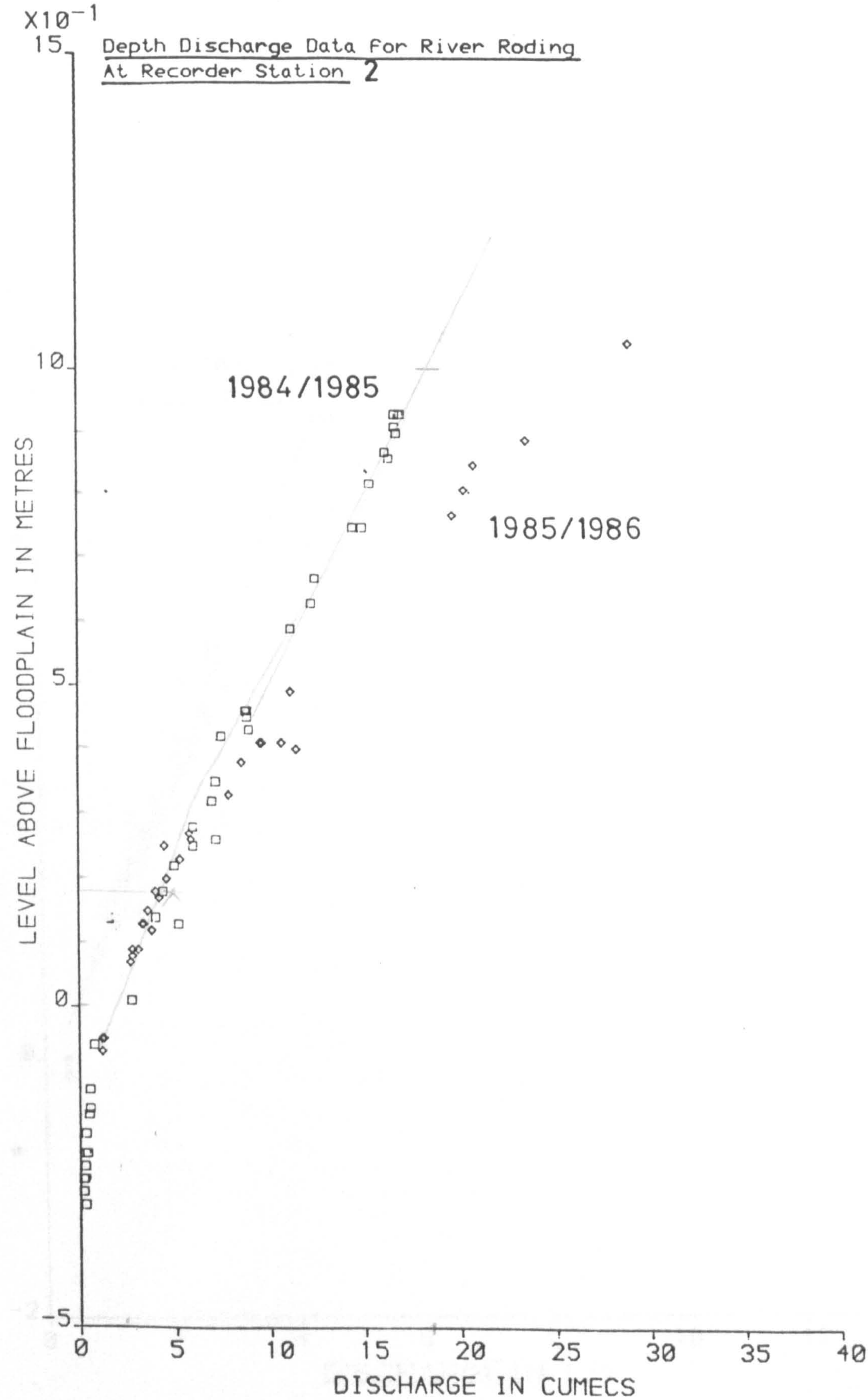


Figure 6.9
Plot of Prototype Depth-discharge Curves for Recorder 2
for 1984/1985 and 1985/1986 Wet Seasons

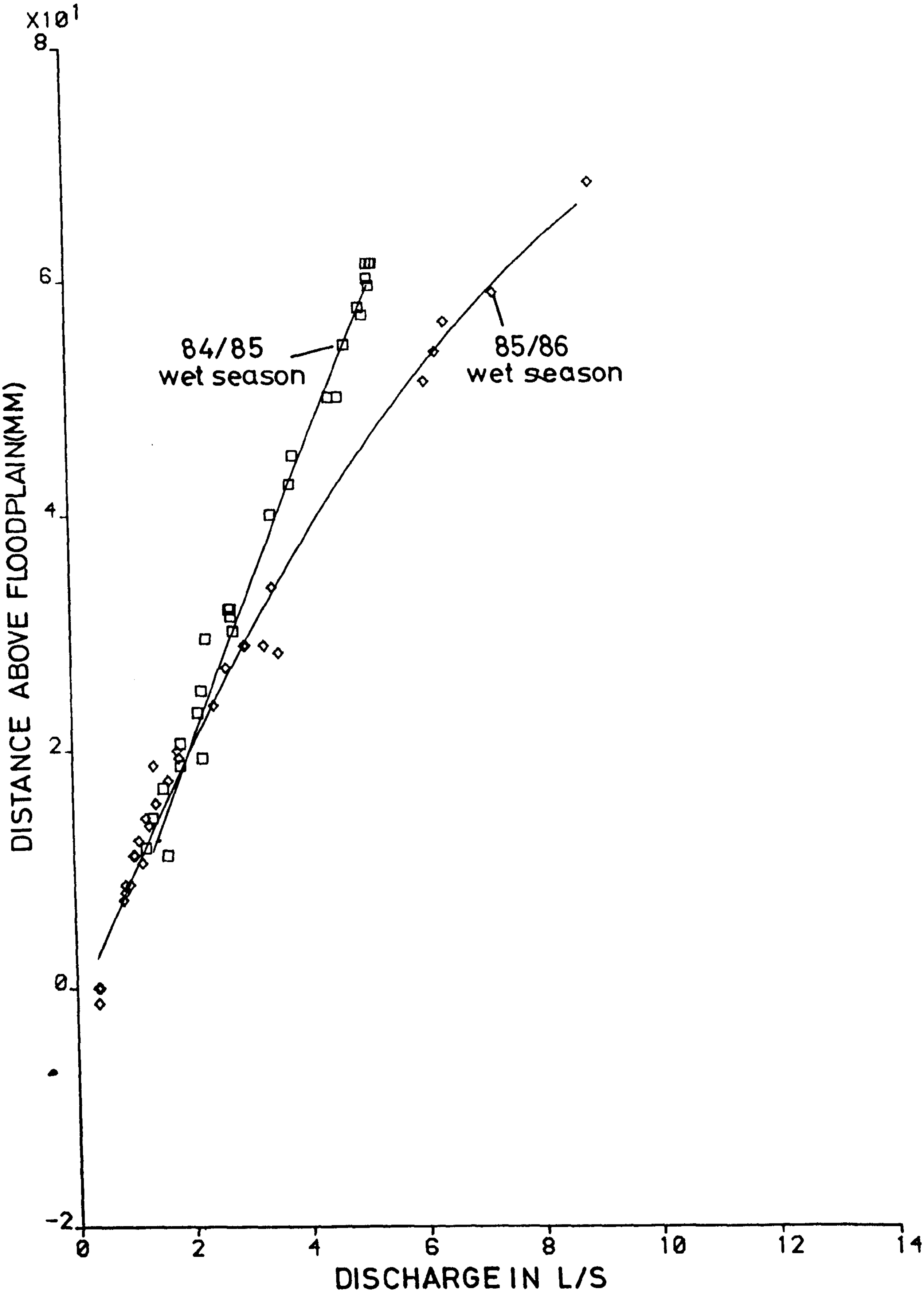


Figure 6.9b
Plot of Recorder 2 Depth-Discharge Data above Floodplain Level Scaled to Model Values and Best Fit Curve Superimposed

different section of river downstream of it, **(chapter 5)**. The data from recorder 2 have been scaled to model values and replotted in figure 6.9b . Superimposed on the data are best-fit 3rd order polynomial curves for each set of points. (These were produced with a numerical analysis software package on a ma inframe computer).

Model depth-discharge Series 1,2 and 3 have been plotted in figure 6.10 . The fitted curves from figure 6.9b have been superimposed on the model data with the 10% discharge error bands. Series 3 closely matches the 1985/1986 prototype data, with the exception of the peak flows where the model data begins to tail off. It seems, therefore, that the flexible roughness chosen, modelled fairly closely the cut state of the floodplain for almost the entire range of flows.

An explanation for Series 1 flattening off and diverging from the river data at high discharges could have been due to the lack of roughness along the side walls of the floodplain, which, on inspection of the aerial photographs had significant amounts of vegetation growing on them. Due to the exaggeration of scale in the model it is likely that the side walls would have assumed greater significance.

6.4.2 Detailed Roughening

It remained then to increase the model roughness to match the 1984/1985 flows and take the side wall effect into account. Series 4,5 and 6 attempted to do this.

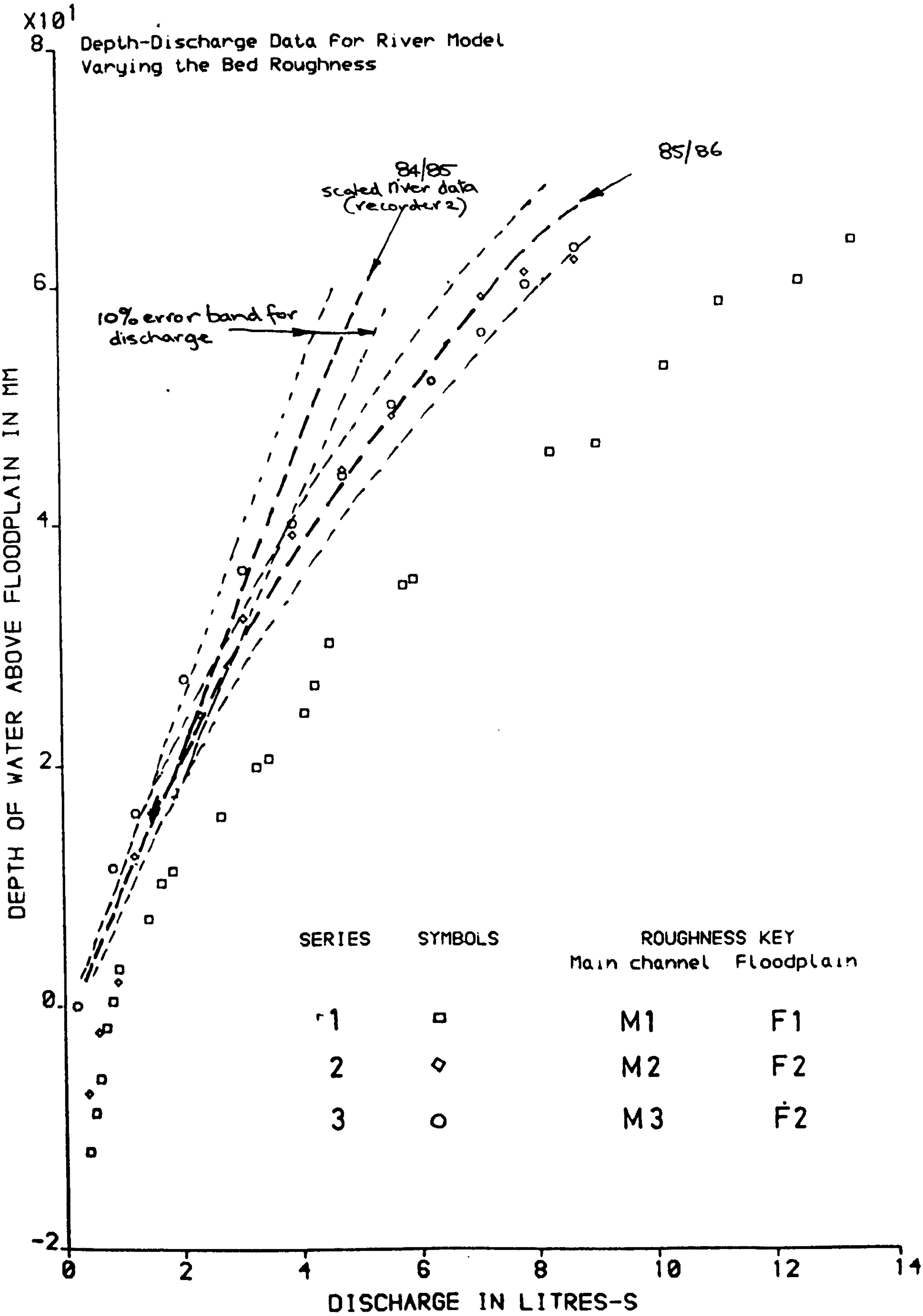


Figure 6.10
Model Depth-discharge Series 1,2 and 3 with Prototype Data Scaled Down and Superimposed

The roughness types for Series 4,5 and 6 were;

	floodplain	main channel
Series 4 -	Enkamat matting (RR1)	smooth
Series 5 -	Flexible roughness (FX3) on top of enkamat matting (RR1) FX7 up the side walls (photo in fig.6.7)	enkamat + glass spheres
Series 6 -	Flexible roughness (FX3)	enkamat + glass spheres

Enkamat matting was used in Series 4 to try out a different roughness type and Series 5 was an attempt to match the 1984/1985 season by incorporating a dense undergrowth in the form of the matting (RR1), with flexible vegetation on top together with the addition of side wall roughness. The result was a floodplain far too rough. Series 6, in an attempt to reduce the roughness, had no Enkamat on the floodplain but it too was still unsatisfactory. Figure 6.11 is a plot of the rating curves for series 4 to 6 with the prototype data superimposed as for figure 6.10. The lack of fit is clear.

It appeared therefore that although the 1985/1986 prototype data could be successfully compared, it was not possible to extend it to the 1984/1985 data without substantial changes in the roughness.

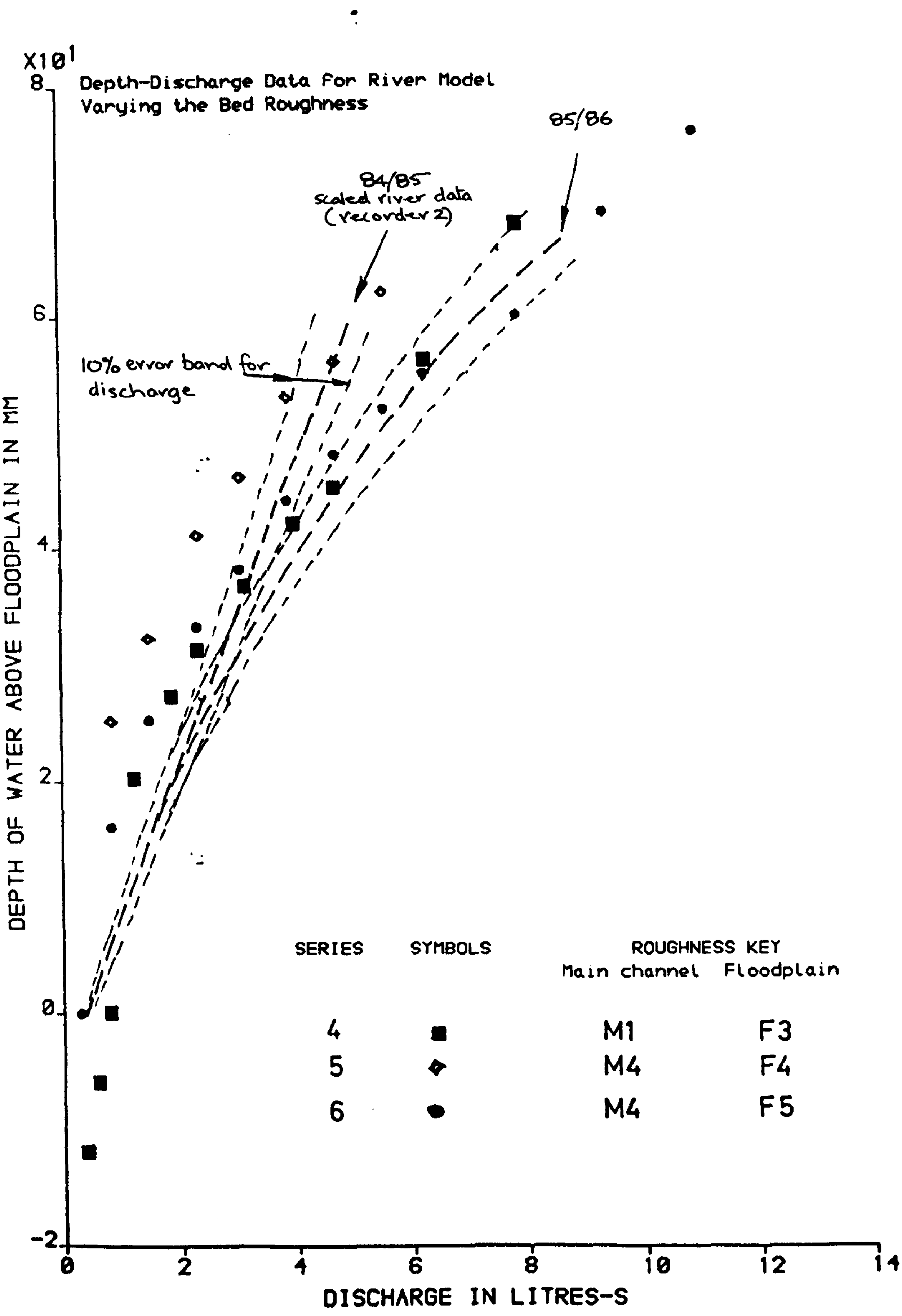


Figure 6.11
Model Depth-discharge Series 4,5 and 6 with Prototype
Data Scaled Down and Superimposed

At this stage it was decided that another roughness element was required and so RR3 - rigid cylindrical roughness elements were introduced. Series R1 through to R5 and plotted on figure 6.12 were the results of progressively roughening the model with the aim of reducing the level of water at lower flows whilst maintaining sufficient roughness at high overbank levels. For this exercise it was only necessary to produce 2 or 3 critical points on each curve. The R, or roughening, series eventually produced the fully roughened curve equivalent to the 1984/1985 river data, Series 7 (Figure 6.14). The DR, or de-roughening, series, figure 6.13, subsequently led to Series 8, the model equivalent of the 1985/1986 river data.

As can be seen from the curves in figure 6.14, Series 8 matches well the prototype data, although there is some 'tail off' at high discharges. Series 7 although still within the error band could not be altered to fit the curve. Maximum rigid roughness had been applied to the floodplain, non-submerged RR3 in a 25mm by 35mm grid together with a wide main channel roughness margin at twice the density. At low discharges this was sufficient. Vegetation roughness on the side wall was considerable, FX6. Without physically reducing the width of the floodplain to 'push' up the slope of the curve, an option that did not seem justifiable, it was decided to use Series 7 and Series 8, as they stood, as equivalent to the prototype data. The remaining experiments on the model were primarily aimed at the difference between proposed management schemes. It seemed possible that the model could not reproduce the turblent losses experienced in the reach at high roughness states, which on account of the dense vegetation on the floodplain was very complex.

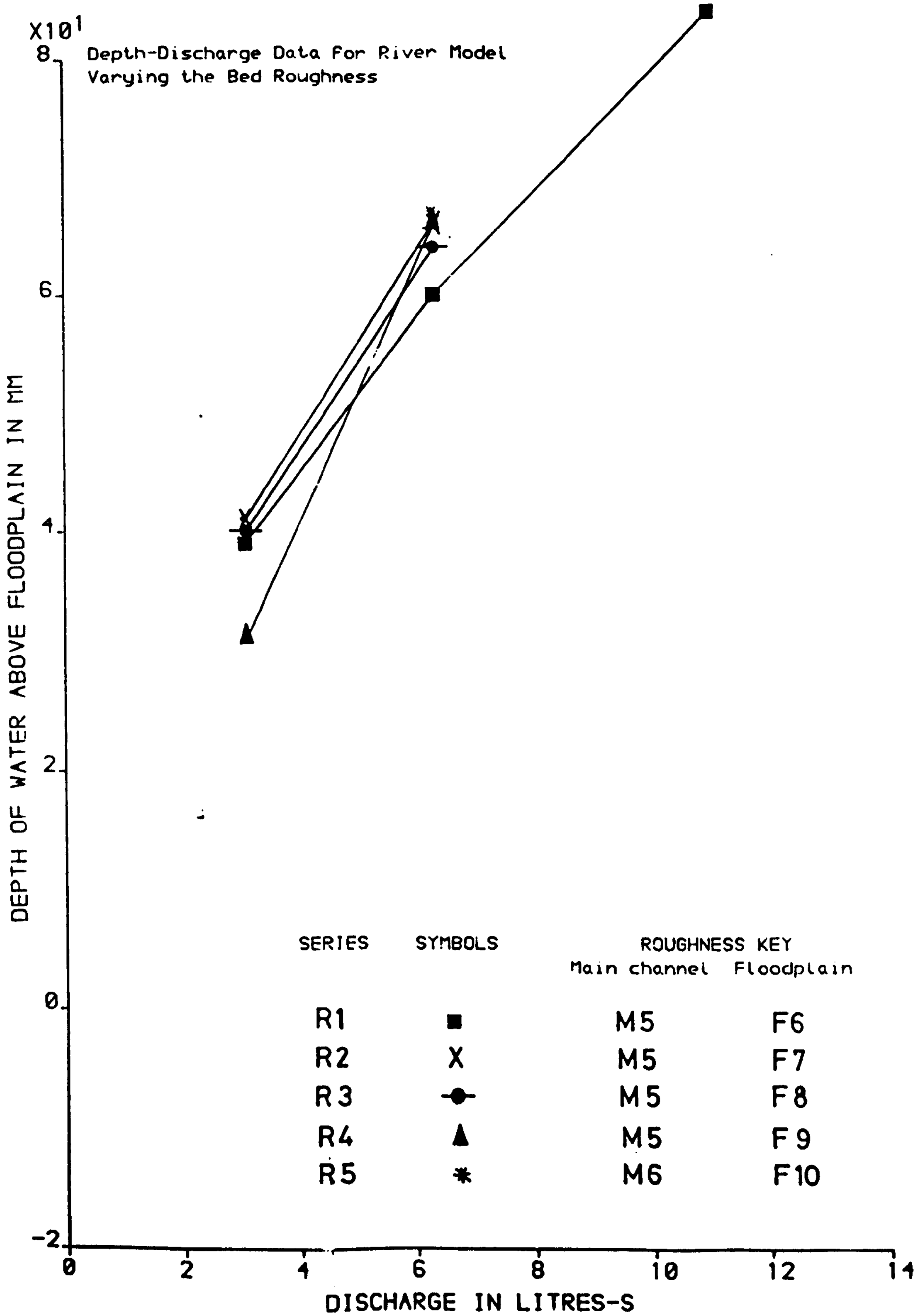


Figure 6.12
Model Series R1,R2,R3,R4,R5

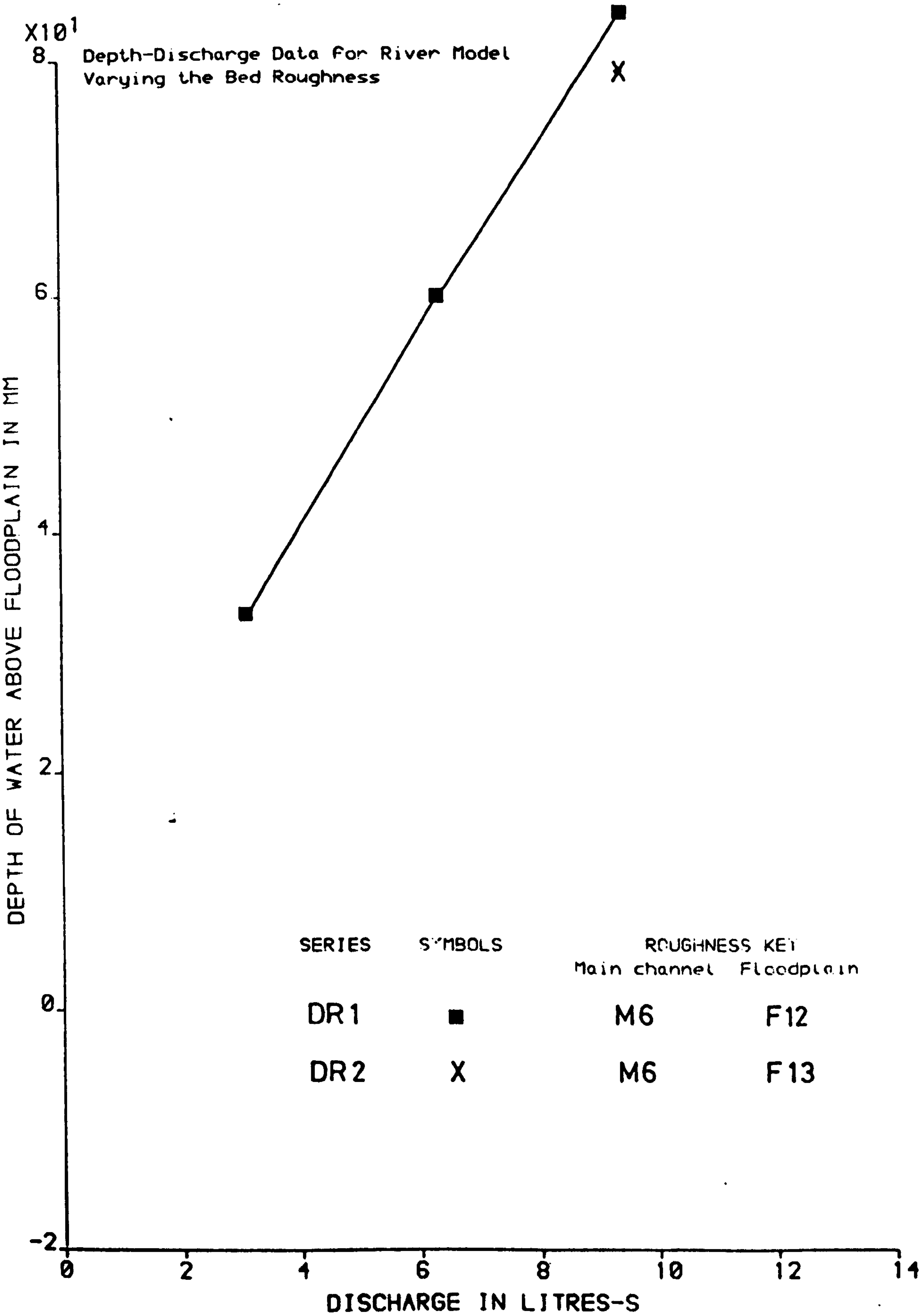


Figure 6.13
Model Series DR1,DR2

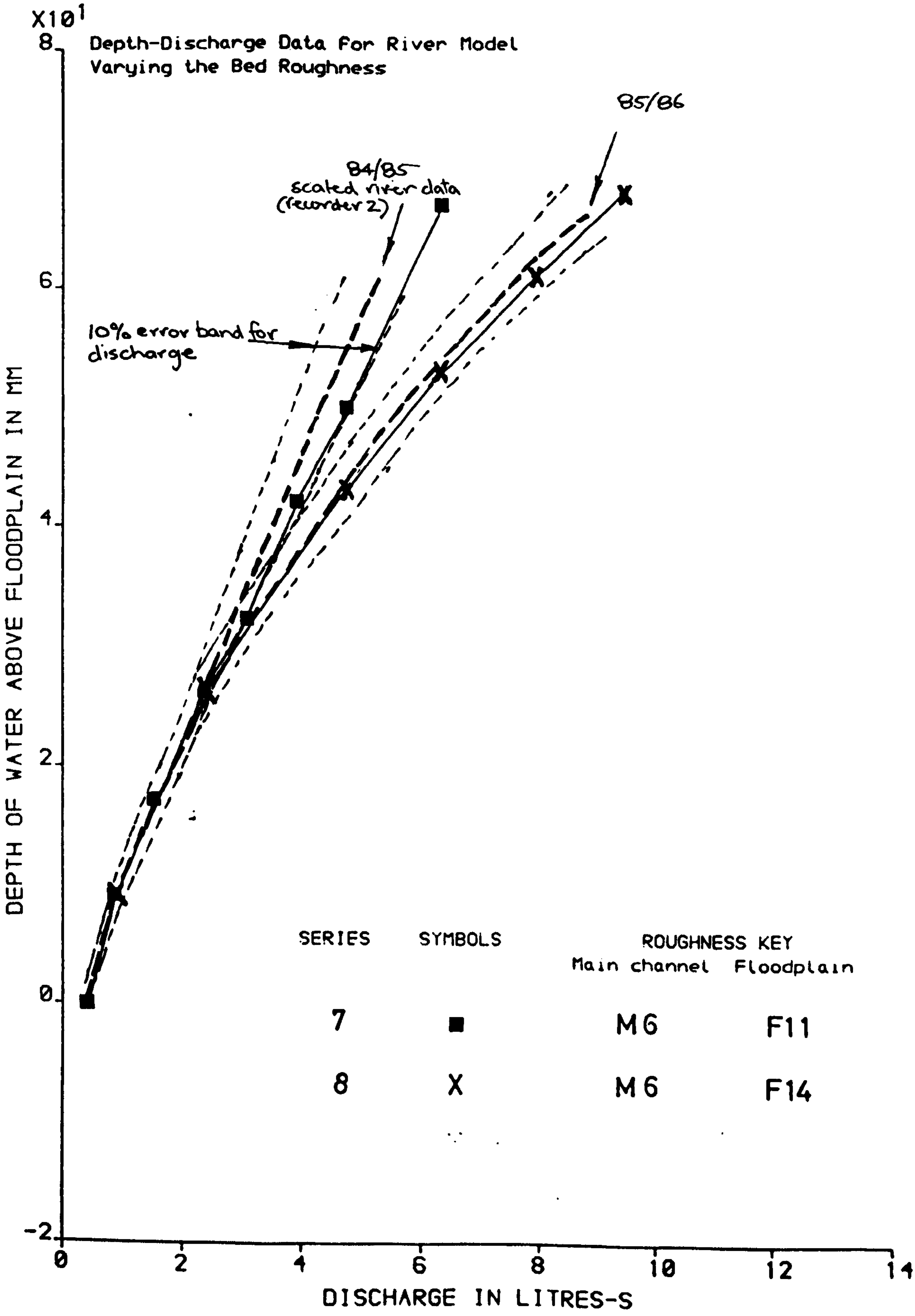


Figure 6.14
Model Series 7,8 with Prototype Data Scaled Down and Superimposed

Figure 6.14b

Photograph of Fully Roughened Model - Series 7

6.5 Working Model

Series 7 and 8 represent the laboratory equivalent of the available prototype data. All flexible roughness had been abandoned in favour of cylindrical rigid roughness elements, with the exception of side wall roughness in Series 7. The deviation from realistic roughness had to be made as it had become apparent that small scale roughness could not sustain turbulent losses all the way to the fluid surface in the model, a condition which had been observed on the prototype by the evidence of large turbulent eddies erupting to the surface of the river during periods of high flow.

Roughness coeficients for Series 7 and 8 have been evaluated at section Y=4730 by the 'single channel method' and presented in appendix A.6. Manning 'n' values vs overbank depth for both series are plotted in figure 6.15. A bankfull 'n' value of 0.05, and maximum values of 0.055 and 0.04 were recorded for S7 and S8 respectively. Bankfull and maximum 'n' values for '84/'85 and '85/'86 from the prototype data at recorder 2 were, .044, .045, .031 .

In the distorted model, depth averaged velocities were equated to the prototype as discussed in section 6. A depth averaged velocity profile at section 1.031 was produced from the velocity traverse mentioned in chapter 5. This was compared with depth averaged velocity traverses carried out on the model (covered in detail in chapter 7) for approximately equivalent roughness conditions. The predicted model profile, scaled to prototype values agrees fairly well with the actual traverse, figure 6.16.

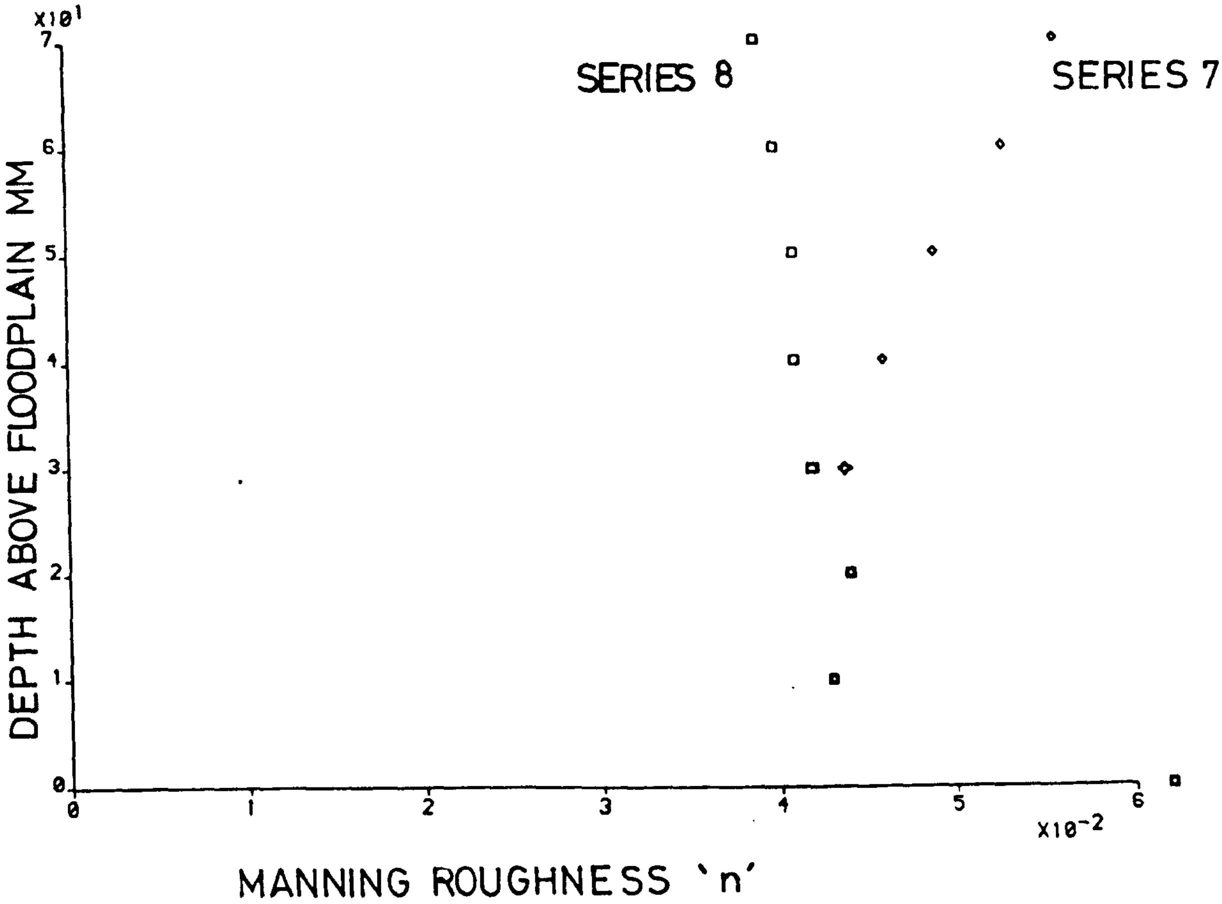


Figure 6.15
Plot of Manning Roughness 'n' vs Depth of Flow Overbank
for Series 7 and 8

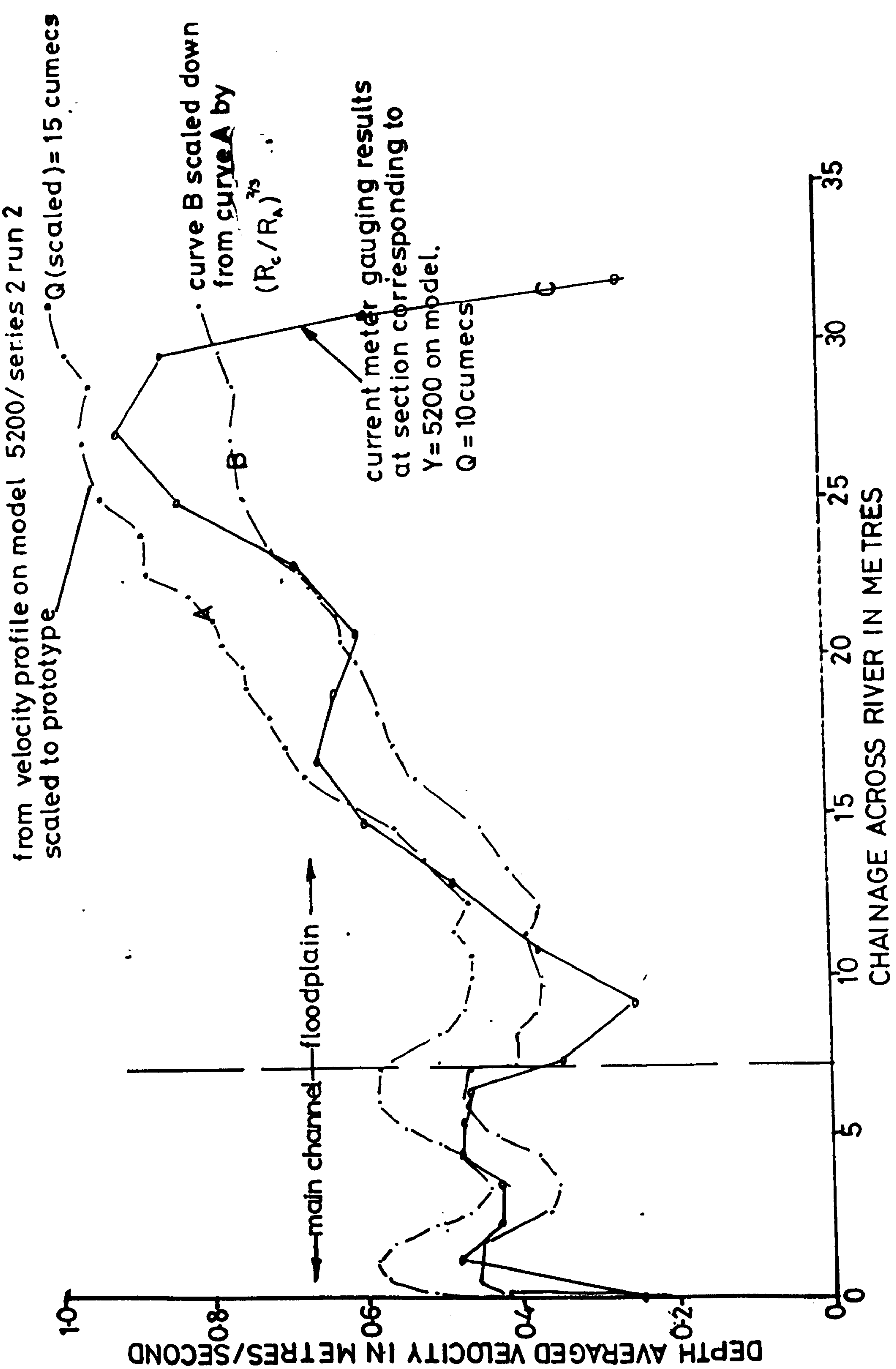


Figure 6.16
Depth Averaged Velocity for Model at Y=5200 Scaled and Compared with Prototype

NOTES ON ROUGHNESS TYPES

To simplify the presentation of the roughness type table various phrases have been used as shorthand:

FX- - the 'FX' series refers to various types of flexible strips punched out of sheets of acetate. A detailed description of them has been given in Appendix A.5 .

RR1 - enkamat matting, type 7720.

RR2 - 10mm dia. pebbles at 20mm centres.

RR3 - wire rods , 2.5 mm diameter of various lengths. Grid spacing is defined as 'lateral spacing' in mm by 'longitudinal spacing'in mm with the orientation along the flume. Given height is the length of wire above the floodplain surface.

marginal roughness - roughness positioned within area of floodplain adjacent to main channel approximately 40mm wide and running the length of the model on both floodplains where applicable.

reduced marginal roughness - as for marginal roughness but reduced to match river conditions for the 1985/1986 season when selective vegetation cropping took place.

side walls - boundary walls of floodplain.

Table 6.1
List of Roughness Types and Configurations used

Now a working model had been obtained, useful experimental work could be carried out on it. This has been dealt with in chapter 7.

TABLE OF MODEL ROUGHNESS TYPES
IN MAIN CHANNEL

LABEL	DESCRIPTION
M1	painted cement render surface
M2	10mm dia. pebbles at 20mm centres
M3	horsehair matting filling channel
M4	RR1 plus glass spheres
M5	FX3 plus glass spheres
M6	FX5 plus glass spheres

Table 6·1 cont'd

LIST OF MODEL ROUGHNESS TYPES
ON FLOODPLAIN

LABEL	DESCRIPTION
F1	gloss painted polystyrene surface
F2	FX1
F3	RR2
F4	FX3 on top of RR2 marginal FX7
F5	FX3 marginal FX7
F6	FX3 FX4 up side walls
F7	FX3 plus RR3 at 40mm by 100mm grid, non-submerged FX4 up side walls
F8	FX1 plus RR3 at 40mm by 70mm grid, non-submerged. FX4 up side walls
F9	FX1 plus RR3 at 40mm by 70mm grid, non-submerged FX6 up side walls
F10	RR3 at 40mm by 35mm grid, non-submerged FX6 up side walls
F11	RR3 at 40mm by 35mm grid, non-submerged marginal RR3 at 25mm by 35mm grid, non-submerged FX6 up side walls
F12	RR3 at 40mm by 35mm grid, 40mm height marginal RR3, 25mm by 35mm grid, non-submerged FX6 up side walls
F13	RR3 at 40mm by 35mm grid, 30mm height reduced marginal RR3, 25mm by 35mm grid, non-submerged FX6 up side walls
F14	RR3 at 40mm by 35mm grid, 30mm height reduced marginal RR3, 25mm by 35mm grid, non-submerged
F15	RR3 at 40mm by 35mm grid, 30mm height reduced marginal roughness RR3, 25mm by 35mm grid, 30mm height
F16	RR3 at 40mm by 35mm grid, 30mm height marginal roughness RR3, 25mm by 35mm grid, non-submerged
F17	RR3 at 40mm by 35mm grid, 30mm height marginal roughness RR3, 25mm by 35mm grid, non-submerged RR3 at 40mm by 35mm grid, non-submerged at selected bends

Table 6.1 cont'd

CHAPTER 7

Laboratory Experimentation On River Roding Model

Chapter 5 dealt with the preliminary work which had been necessary to prove the model. Constructive experimentation could now be embarked upon and, from the similarity established between model and prototype it would be possible to relate the results from the model studies to the river.

The main aims of the experimental work were to investigate the stage-discharge characteristics and flow patterns in the Flood Alleviation Scheme whilst it was in a flooded state. Various floodplain/main channel roughnesses were used to simulate different vegetative conditions within the river. Minor changes to the floodplain geometry were made to assess the effect of reducing the form roughness of the floodplain. At a more fundamental level, experimentation to investigate the flow interaction between the meandering main channel and floodplain was also carried out.

Stage discharge curves have been established from longitudinal water surface profiles according to the method described in chapter 6. Mean principal flow velocities at points across various sections were measured. Surface flow patterns have been photographed.

Analysis of the model data presented here has been left until chapter 8.

7.1 Stage-Discharge Curves

Knowledge of the water surface level in a reach for a given discharge is of prime importance to the river engineer. In the case of the River Roding Flood Alleviation Scheme, known stage-discharge characteristics were necessary to determine the capacity of the river and hence its ability to accommodate flood flows.

Six alterations were made on the model once similarity had been established. A combination of different roughness states on the floodplain and in the main channel were utilised, together with a physical alteration to the floodplain boundaries.

Two states of the river had been monitored over successive wet seasons. The first represented an extreme state of floodplain roughness, with no cropping of the vegetation on the floodplain and the main channel left untouched. The second case was intended to be the implementation of a minimum cutting policy. Reasons for the proposed introduction of this policy as part of a river management scheme have been fully discussed in chapters 1 and 5. This entailed restricting the clearance of floodplain vegetation to areas away from the banks of the main channel, leaving a substantial margin of dense reedy vegetation. It had been intended that roughly a 2 metre margin of reeds, adjacent to the main channel, be left the entire length of the monitored reach. Unfortunately, when the floodplain clearance exercise was carried out in the autumn of 1985, the usual time of year to clear the river, the vegetation was overcut and a much reduced margin of reeds remained and none at all in some places.

7.1.1 Modelled Schemes - Vegetative Alterations on Floodplain

A first objective of the modelling programme, therefore, was to assess the effect of leaving a two metre margin of reeds adjacent to the main channel to conform to the proposed wildlife conservation aspect of the scheme. The second objective was to determine the capacity of the reach with all the floodplain vegetation cropped, a policy normally followed by TWA but not as of yet monitored in the field.

It has been observed in some of the flow visualisation experiments (described further on in this chapter) that separation of flow occured at sharp meander bends within the model leaving a portion of the floodplain with a low flow velocity and thus low discharge function. It was decided, therefore, that the third objective in the model study would be to assess the effect of leaving vegetation uncut within these areas.

Depth-discharge curves were produced for the three cases, Series 9,10 and 11, by a method described in chapter 6. Longitudinal water surface profiles used to construct the stage discharge curves are presented in appendix A.7 .

Two types of roughness were selected for the floodplain as a result of the preliminary studies, detailed in chapter 6. Cylindrical rigid rods, 2.5mm in diameter, RR3, varying from 30mm in height to non-submerged. Two grid spacings for the rods were used over the floodplain. On the main portion of the floodplain, the grid spacing was 35mm across the flume and 30mm between rods down the flume. Successive rows were staggered to maximise their drag effect. The marginal region, corresponding to a two metre band of reeds in the river and approximately a 40mm strip in the model, had been planted with rods at double the density of the predominant floodplain roughness with a grid spacing of 18mm by 30mm .

The marginal roughness in Series 9, simulating a full growth of reeds, on the prototype, along the main channel bank and described above, was non-submerged for all flow depths. The remaining roughness remained at 30mm. For Series 10, in a simulated complete clearance of the floodplain, all the roughness elements were reduced in height to 30mm, with no change in roughness density. The third run, Series 11, simulated the effect, of retaining vegetation within observed low flow areas on the floodplain, together with a fully restored marginal growth of reeds on the main channel banks, as in Series 9. This entailed reproducing the roughness for Series 9, with the additional factor that some floodplain vegetation was increased in length from 30mm to the non-submerged condition described for the marginal roughness above. In the photograph depicting Series 8 roughness , see figure 6.8 of the previous chapter, the tall marginal roughness elements are clearly visible.

The results are presented in figure 7.1 . Figure 7.2 shows a plan of the River Roding Model, with the roughened areas referred to in Series 9,10 and 11 marked on it. A roughness key can be found in table 7.3, at the end of this chapter. To provide a comparison, superimposed on the three plots are points for Series 7 and 8. As a reminder, series 7 and 8 correspond to the accepted modelled states of the 1984/1985 and 1985/1986 prototype rating curves.

It is clear from a preliminary inspection of the curves, that

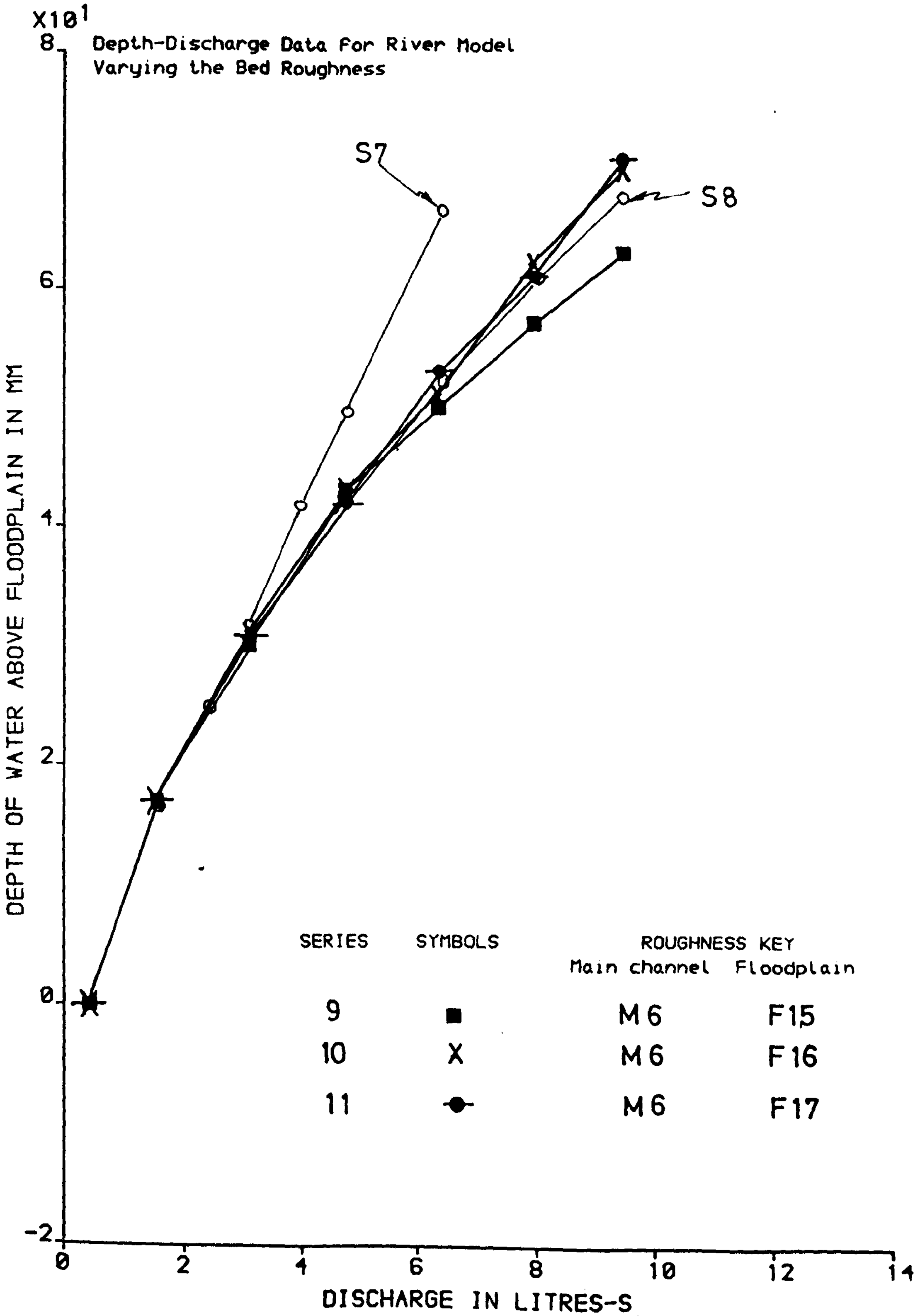


Figure 7.1
Plot of Depth-Discharge Data for River Model, Series 9,10 and 11

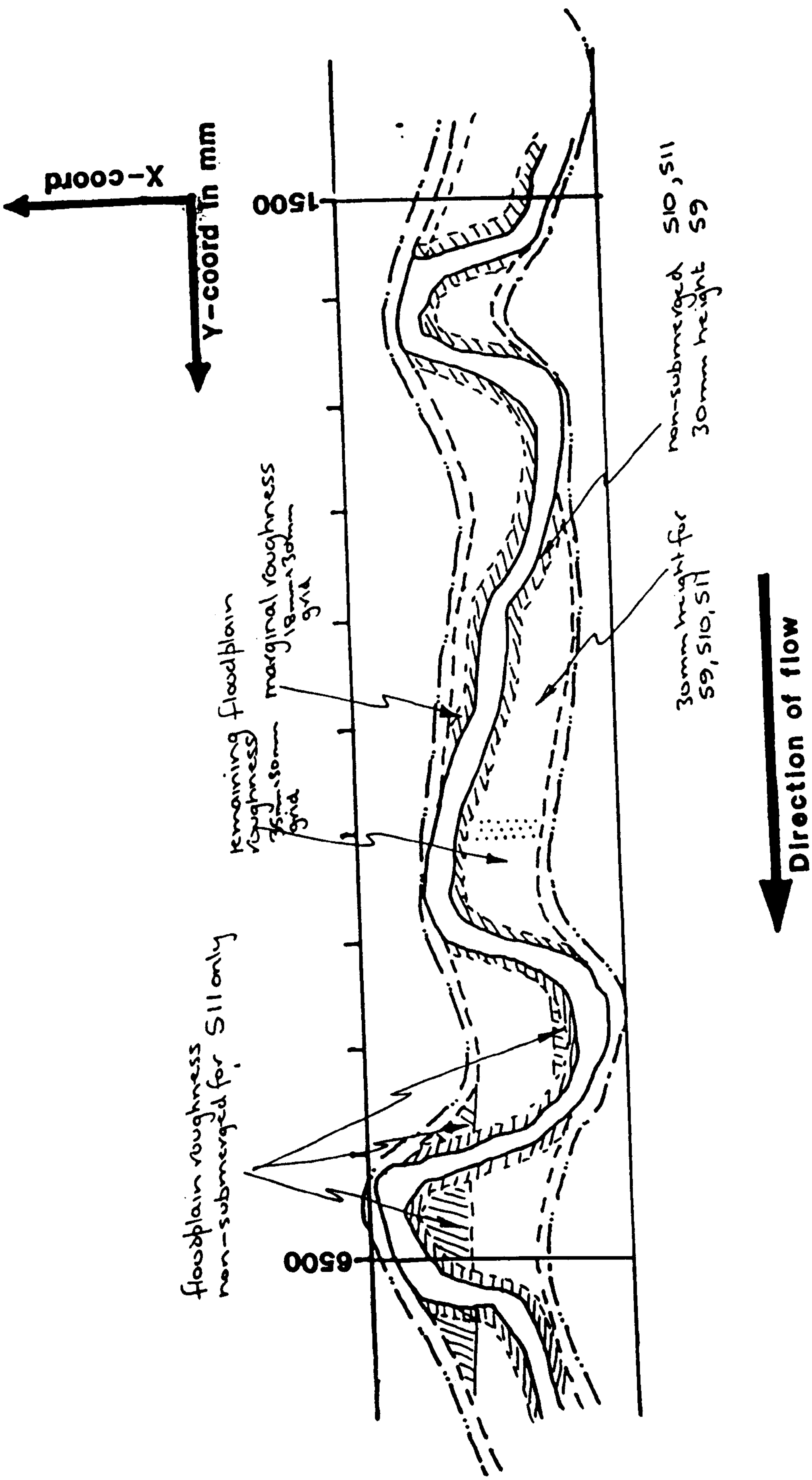


Figure 7.2
Plan of Model Showing Areas of Different Roughness
for Series 9,10 and 11

Series 9 exhibited a marked improvement, and Series 10 and 11 a marginal reduction, in performance compared with Series 8. Thus, it appears that leaving a 2 metre margin (S10) produces a noticeable reduction in discharge capacity over complete clearance of the floodplain (S9). The negligible difference between S10 and S11 demonstrates the minimal impact of leaving vegetation on the inside of selected bends in the model.

7.1.2 Modelled Schemes - Floodplain Boundary Alteration

Based on observation of flow separation at the floodplain bends in the model (described in section 7.3 at the end of this chapter), it was a logical step to gauge the effect of reducing the severity of floodplain bends for various flows and roughness states. In Series 12,13 and 14, an alteration was made to the floodplain boundaries, together with variations of the floodplain and main channel roughnesses. Two bend were smoothed out, with maximum local increases in floodplain width of 25% and 43% . The increase in plan area between the floodplain boundaries and limits of the modelled reach was less than 5% . Details of the alterations are given in figure 7.3 .

As a proposal for improving the capacity of the river, the cost of removing severe bends within the floodplains had to be offset against the possibility of no subsequent floodplain maintenance at one extreme (S13) and a continued minimal maintenance policy (S12), originally applied in Series 11, at the other.The third configuration to be considered was no floodplain maintenance but with regular maintenance and dredging of the main channel (S14).

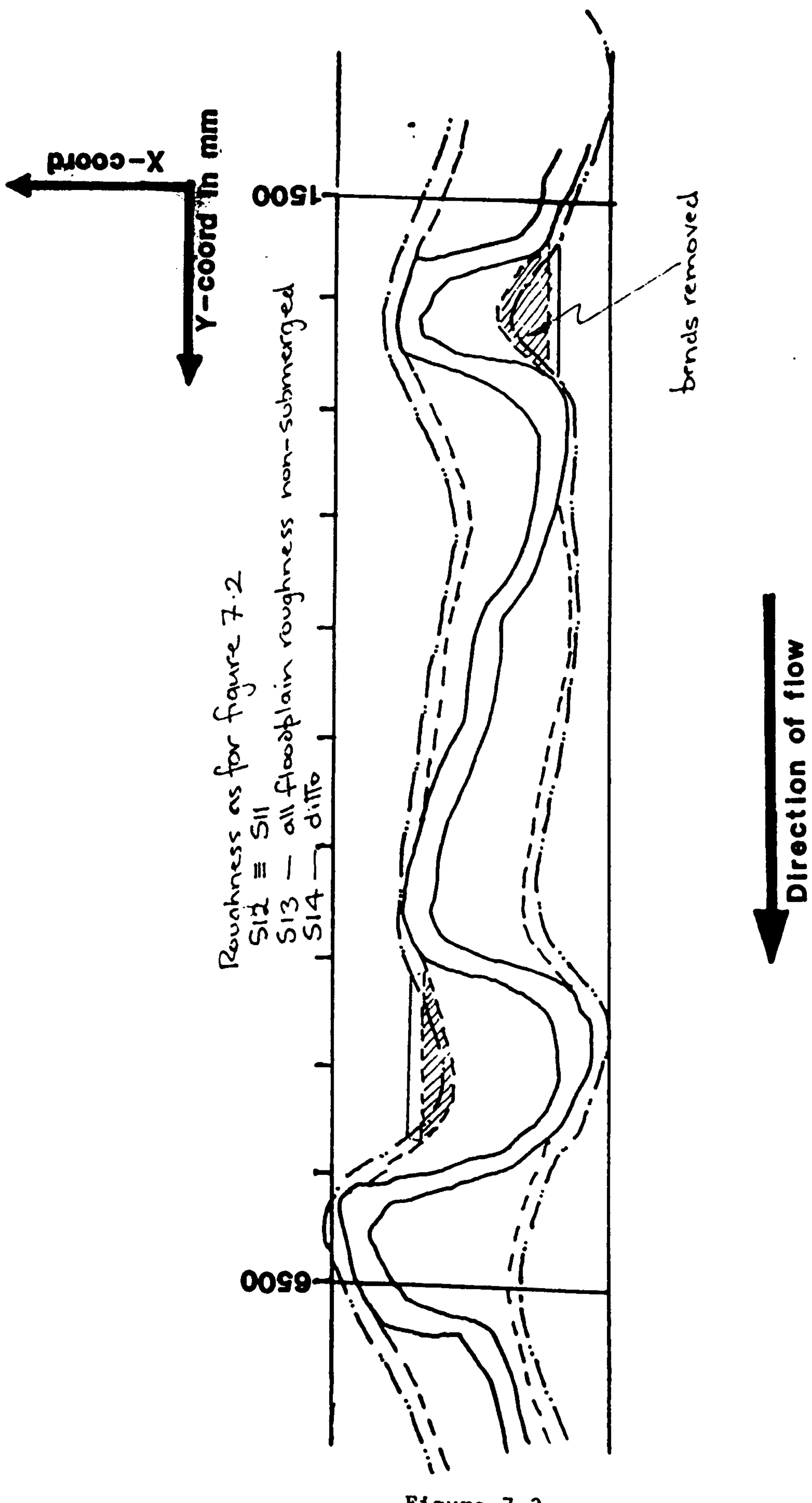


Figure 7.3
Plan of Model Showing Altered Floodplain Banks and Roughness Areas for Series 12,13 and 14

The results are presented in figure 7.4 with Series 7 and 8 superimposed. Series 12 shows a marked improvement over Series 8, a result even more encouraging for the reason that Series 11, in figure 7.1, has the same floodplain roughness and yet showed a reduction in capacity over series 8. This emphasises the significant difference a small alteration to the floodplain boundary can have on the overall form roughness of the reach. Series 13, the return to a fully roughened floodplain, shows a marked improvement over series 7. Clearing the main channel has had some effect at lower discharges but appears to have had little effect on reducing water levels during peak flows.

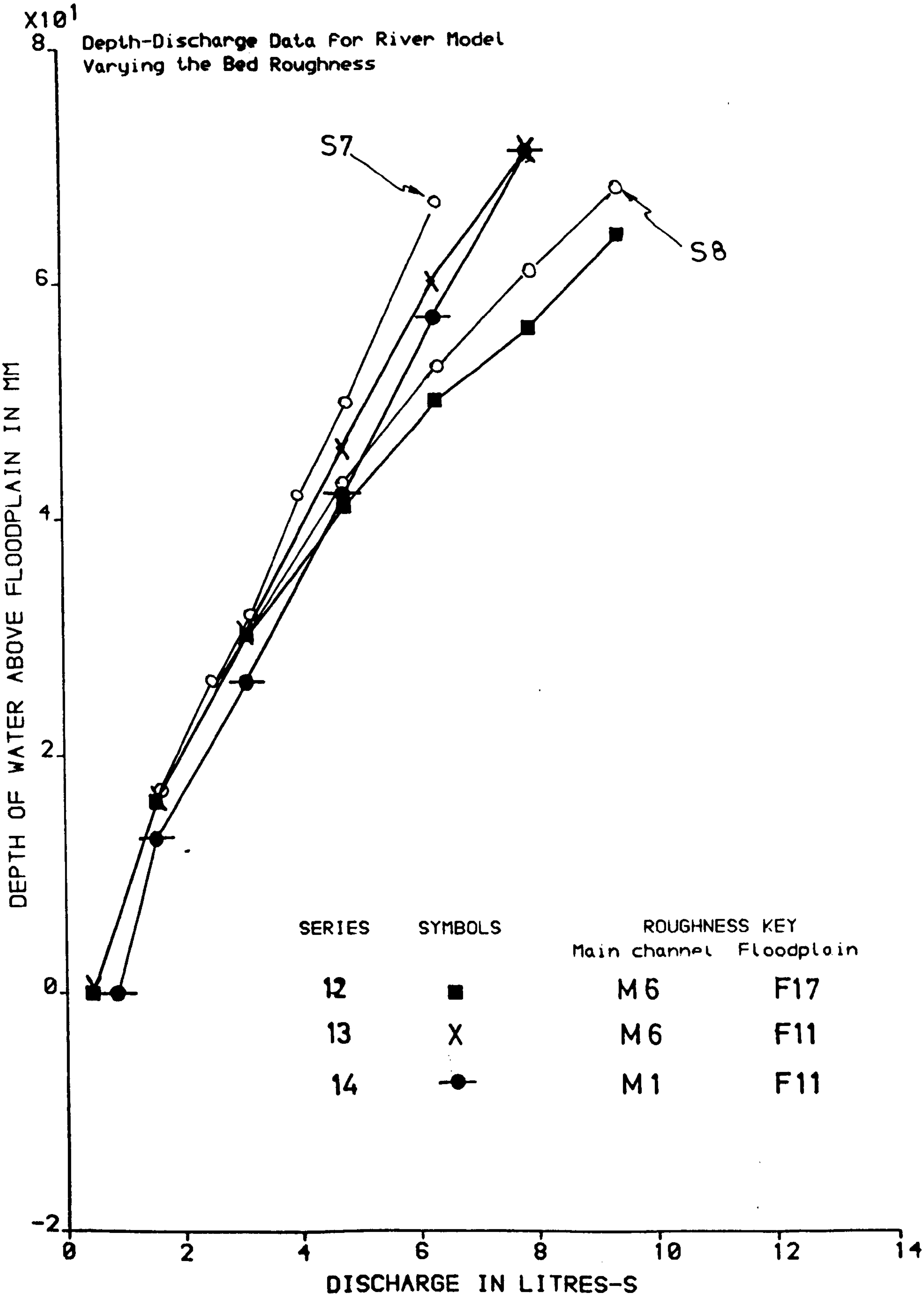


Figure 7.4
Plot of Depth-Discharge Data for River Model, Series 12,13 and 14

7.2 Velocity Profiles

The locations of model cross-sections have been defined according to the X,Y coordinate system introduced in chapter 6 and reproduced in figure 7.5. This shows the positions of the velocity traverses carried out and subsequently reported on in this section.

Isovels, lines of constant velocity, plotted through sections of flow within the model, were obtained by measuring mean point velocities within the flow in a grid pattern. The resulting matrices of velocities, resolved in the principal flow direction, were processed on a main frame computer using numerical analysis routines to produce the isovel maps. The measuring probe was a variable yaw pitot tube developed by the author at the University. It was mounted on an automatic tracking frame, all controlled from a microcomputer. Details of this equipment can be found in chapters 3 and 4.

The recorded isovel plots are included in figures 7.6 to 7.20. 32 plots were constructed in all, for 5 roughness series. Most of the plots were produced for Series 2 and the remainder on Series 1 with the exception of 4 plots split between Series 12,13 and 14.

The isovel plots were carried out primarily to investigate the velocity distribution between general meandering main channel and floodplain flow without regard to the similarity criteria between model and prototype. The reason for this was due to the distortion of the isovels in the model, relative to the prototype, which resulted from the geometrical distortion between the two. However, some of the results, such as the proportion of the total flow in the

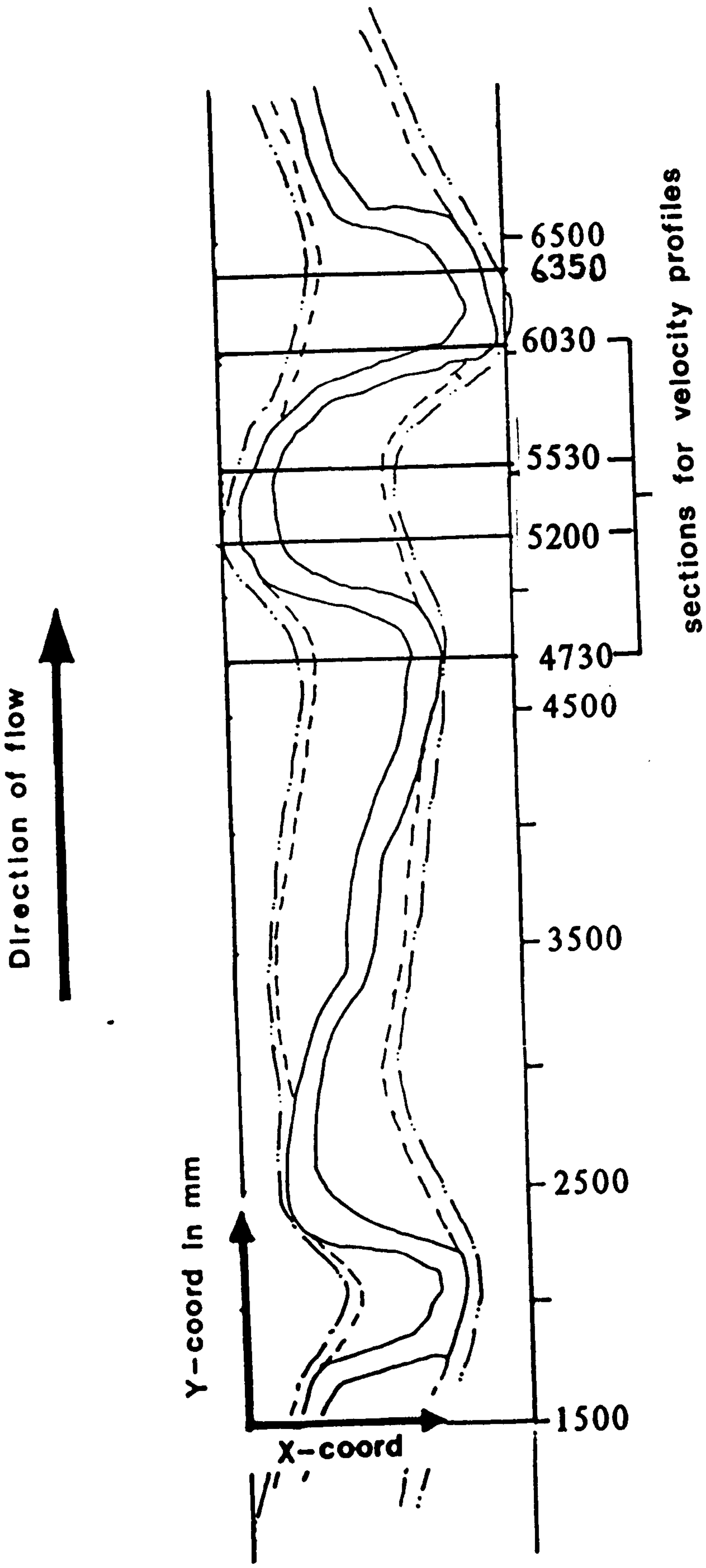


Figure 7.5
Plan of Model Showing Location of Velocity Traverses

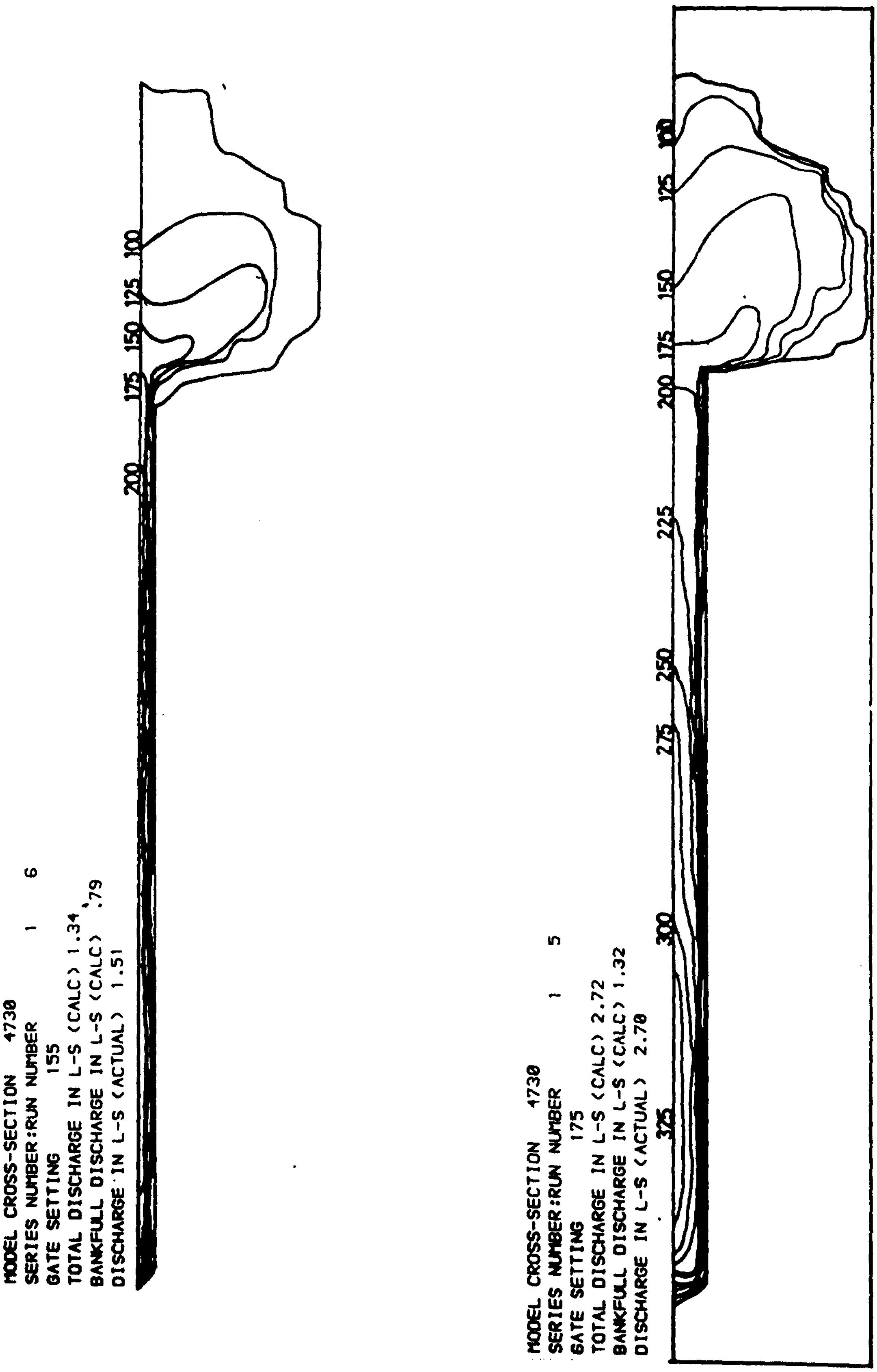


Figure 7.6
Isovel Plots Section 4730-Series 1-Runs 5 and 6
Normal Velocities in mm/s

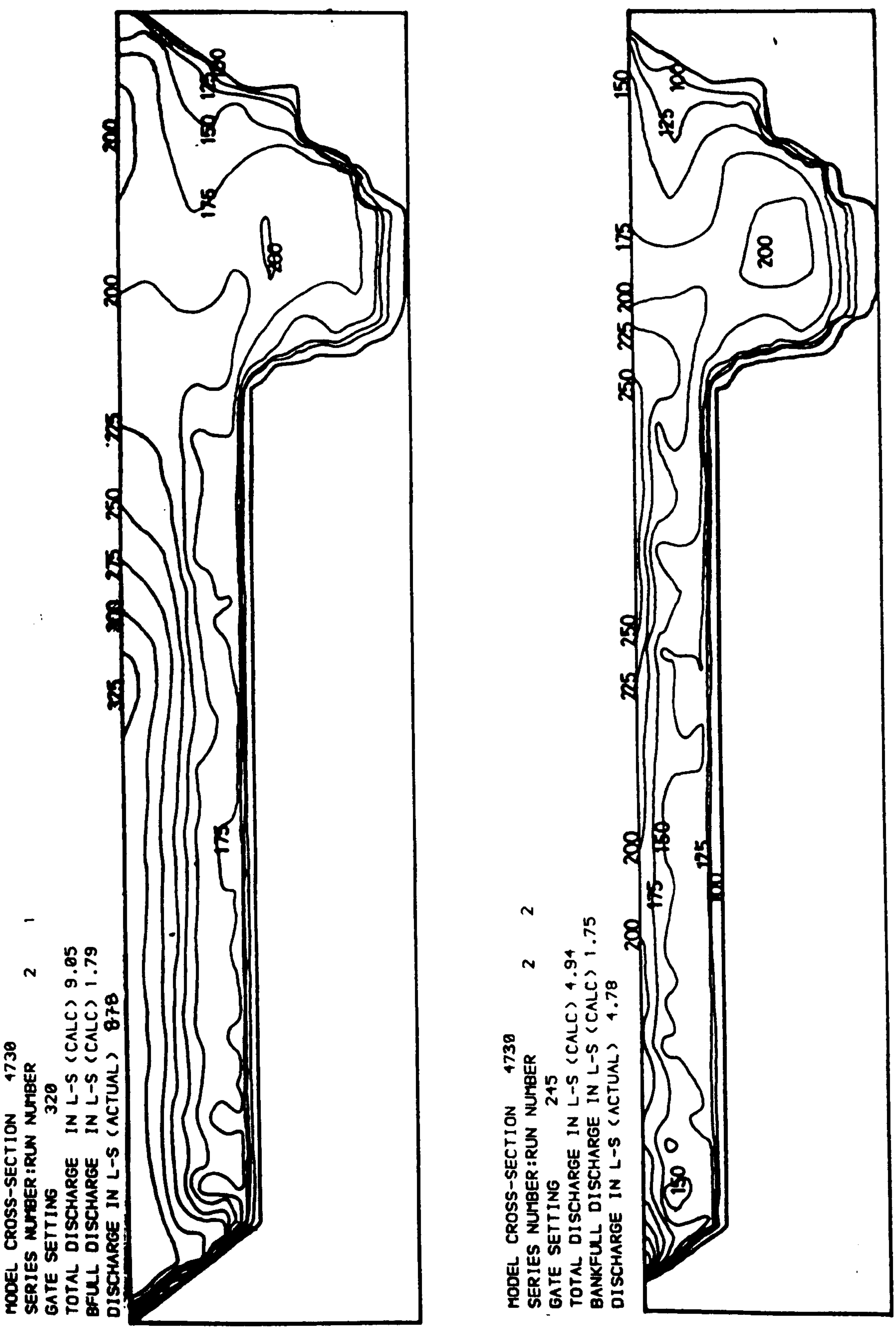


Figure 7.7
Isovel Plots Section 4730-Series 2-Runs 1 and 2
Normal Velocities in mm/s

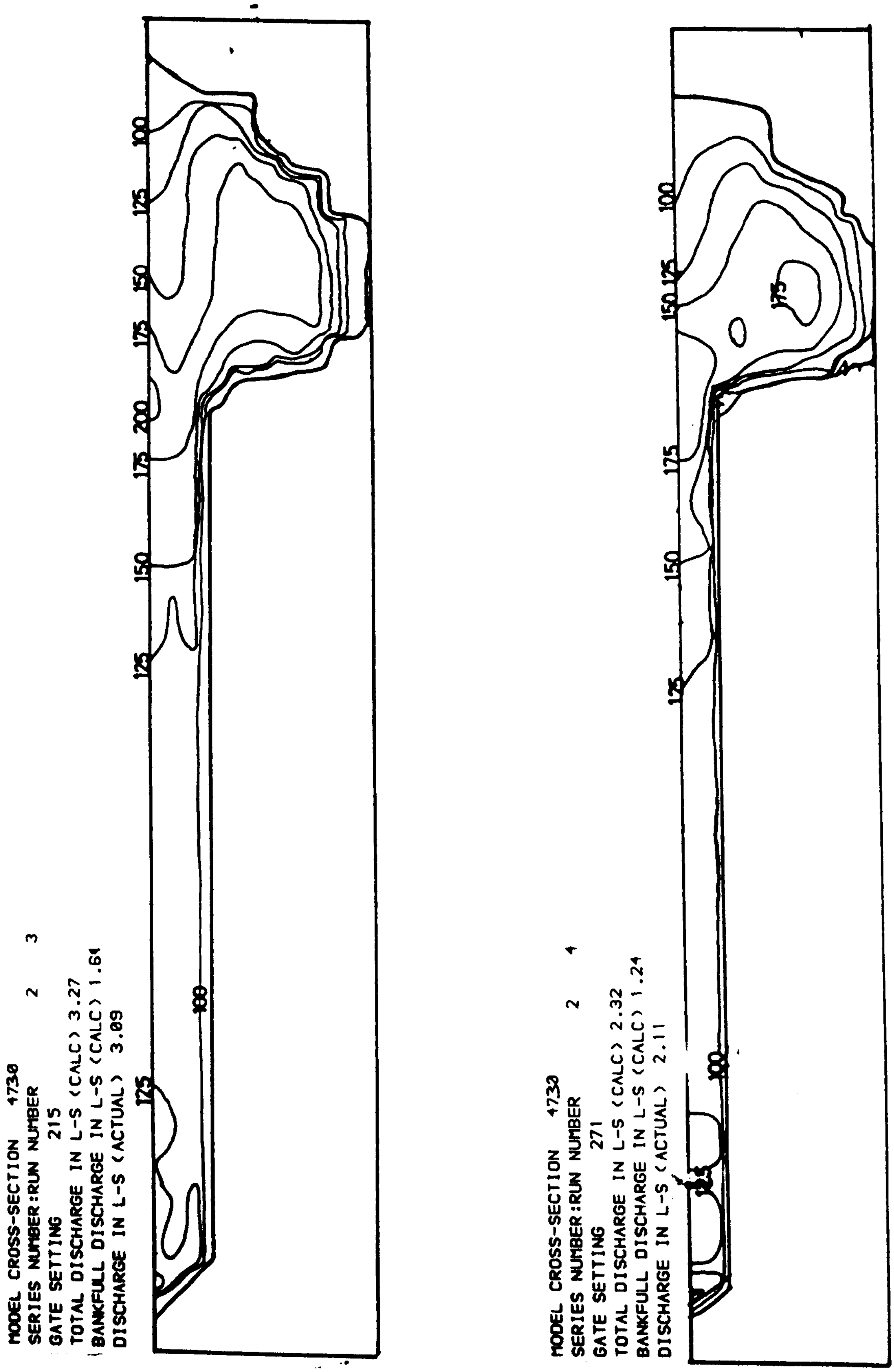


Figure 7.8
Isovel Plots Section 4730-Series 2-Runs 3 and 4
Normal Velocities in mm/s

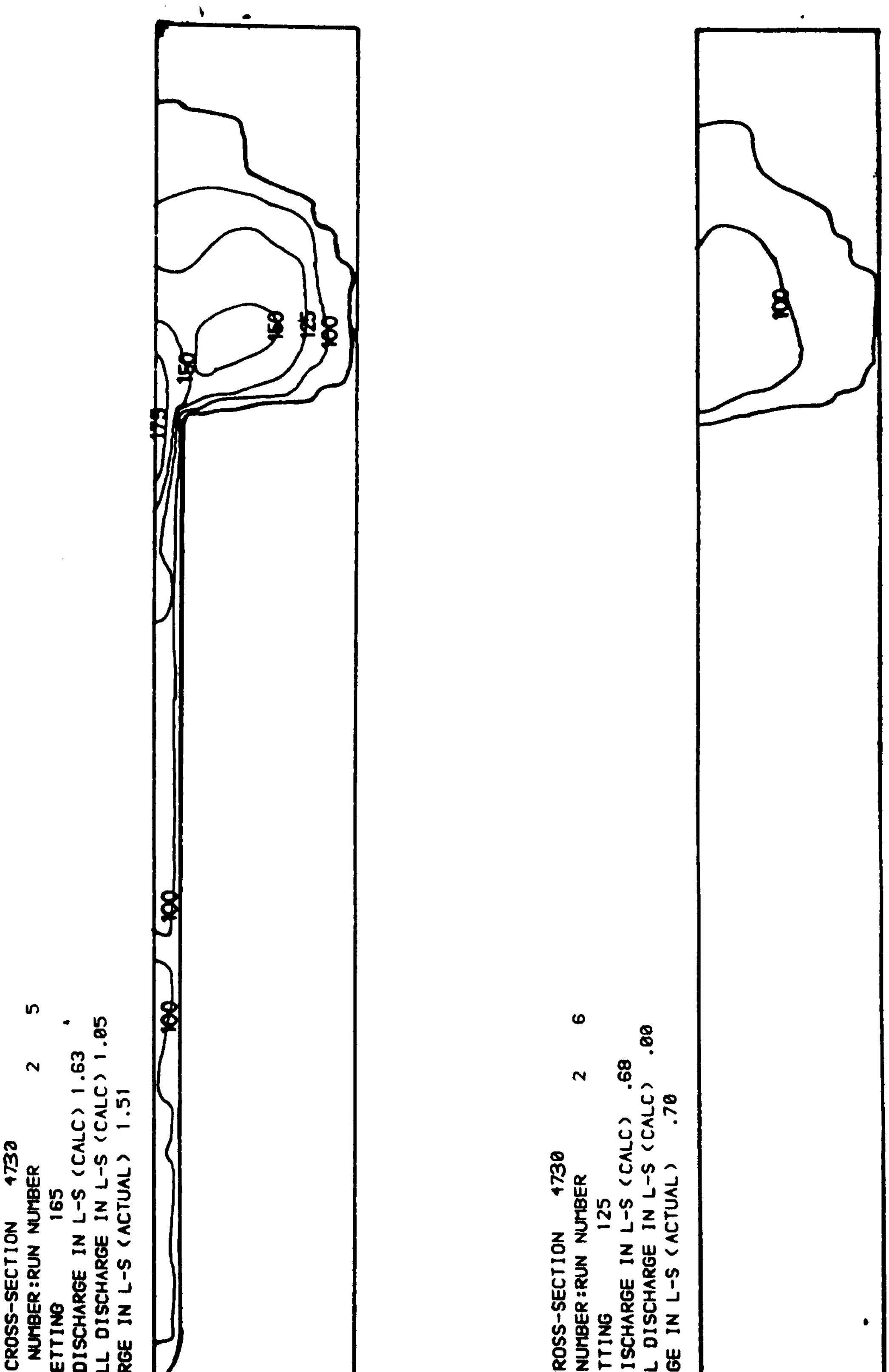


Figure 7.9
Isovel Plots Section 4730-Series 2-Runs 5 and 6
Normal Velocities in mm/s

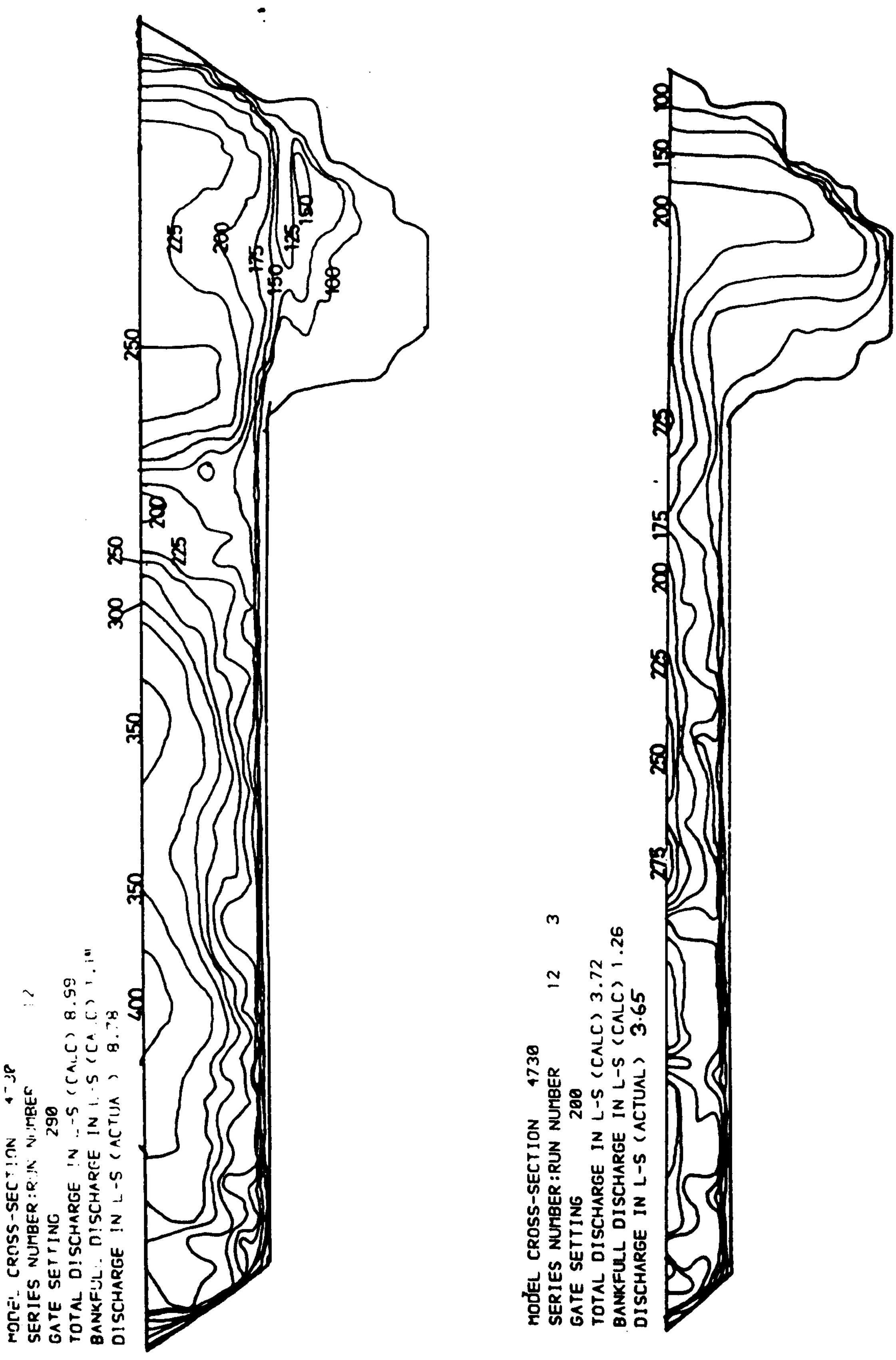


Figure 7.10
Isovel Plots Section 4730-Series 12-Runs 1 and 3
Normal Velocities in mm/s

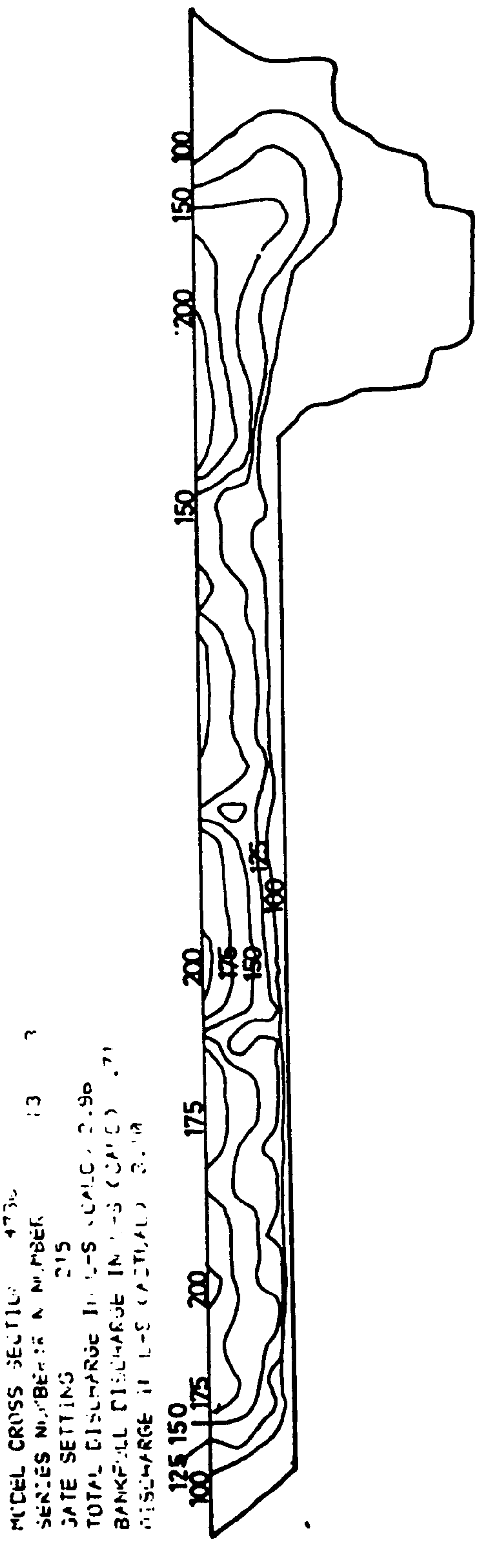


Figure 7.11
Isovel Plots Section 4730-Series 13-Run 3
Normal Velocities in mm/s

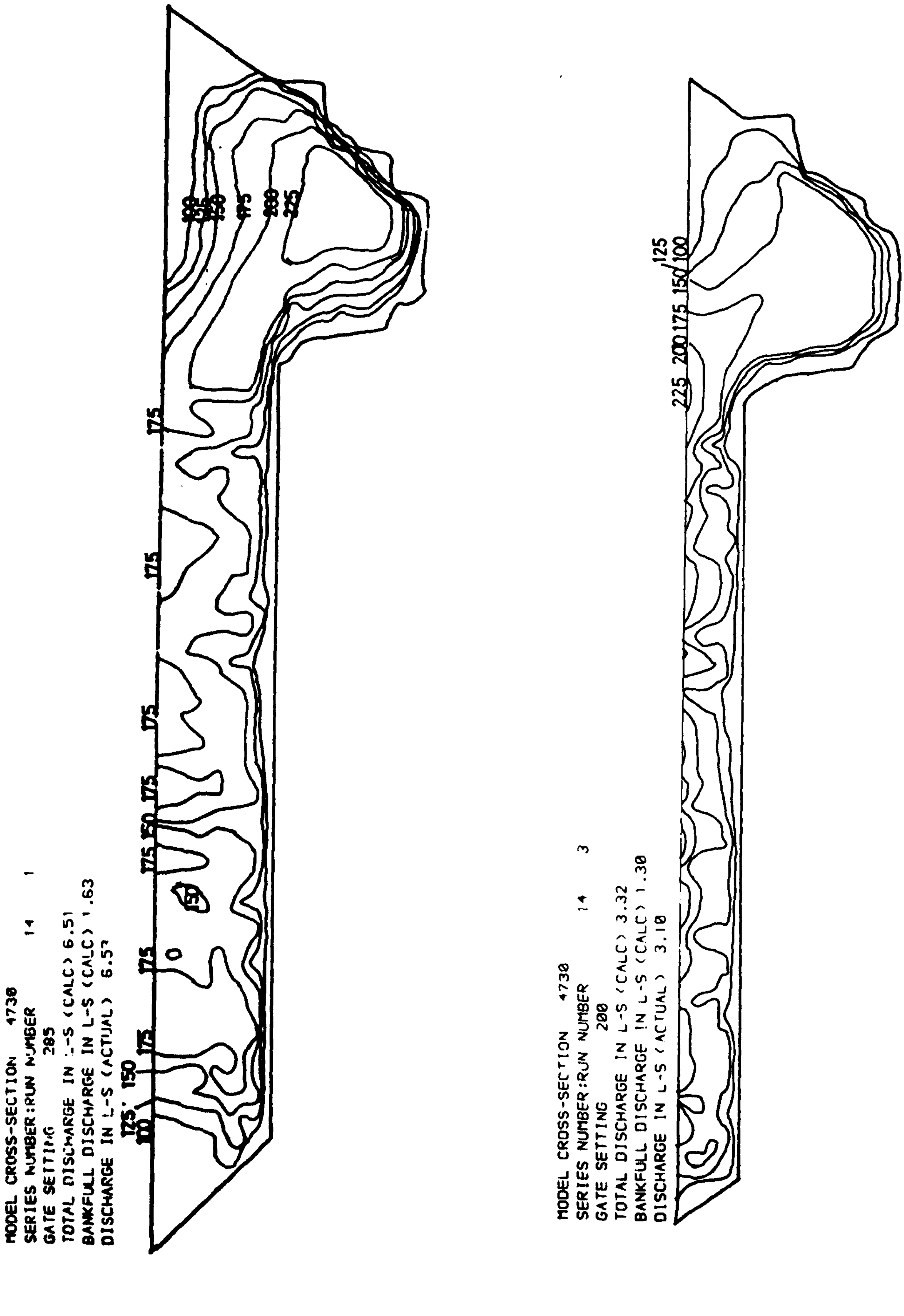


Figure 7.12
Isovel Plots Section 4730-Series 14-Runs 1 and 3
Normal Velocities in mm/s

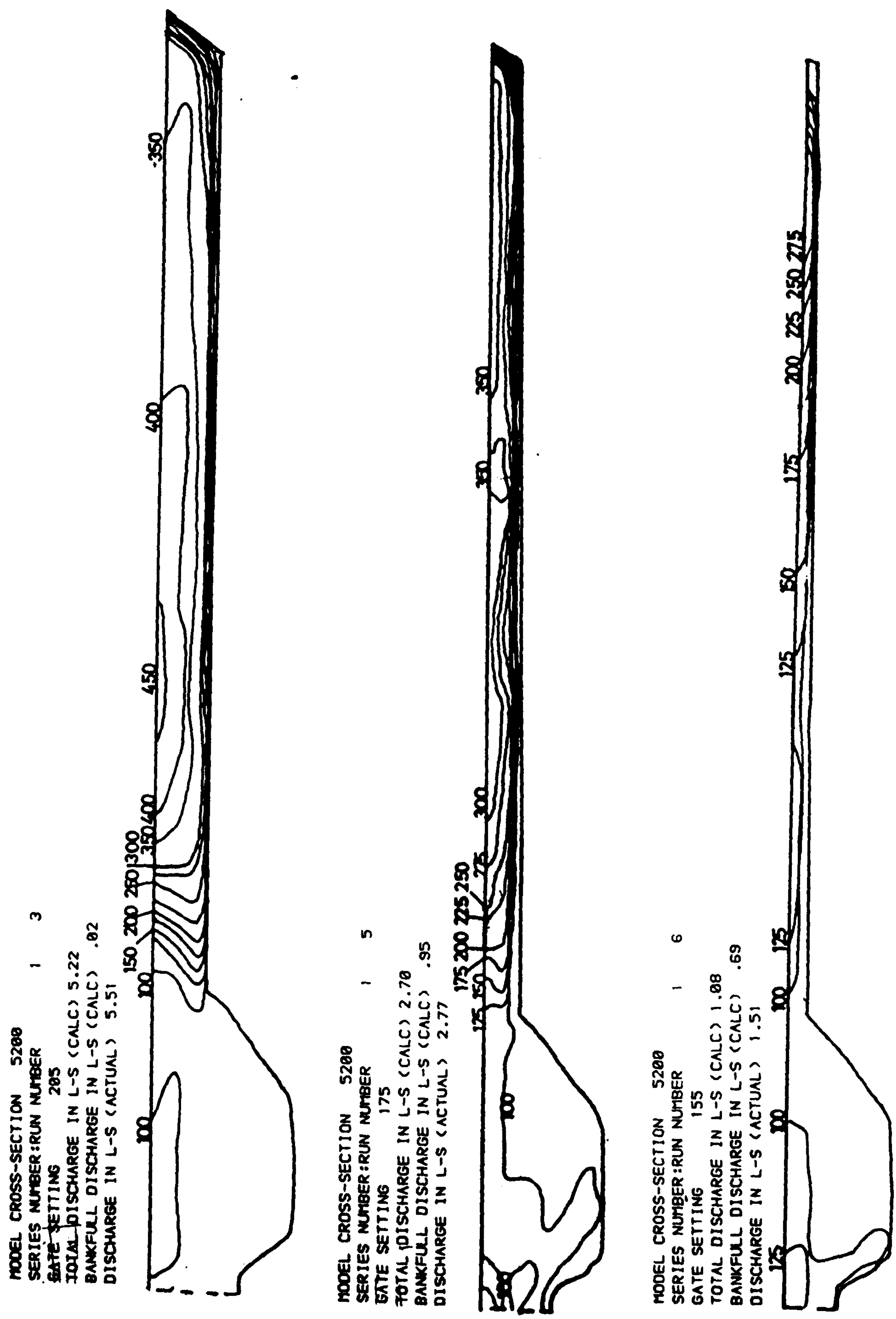


Figure 7.13

Isovel Plots Section 5200-Series 1-Runs 3,5 and 6
Normal Velocities in mm/s

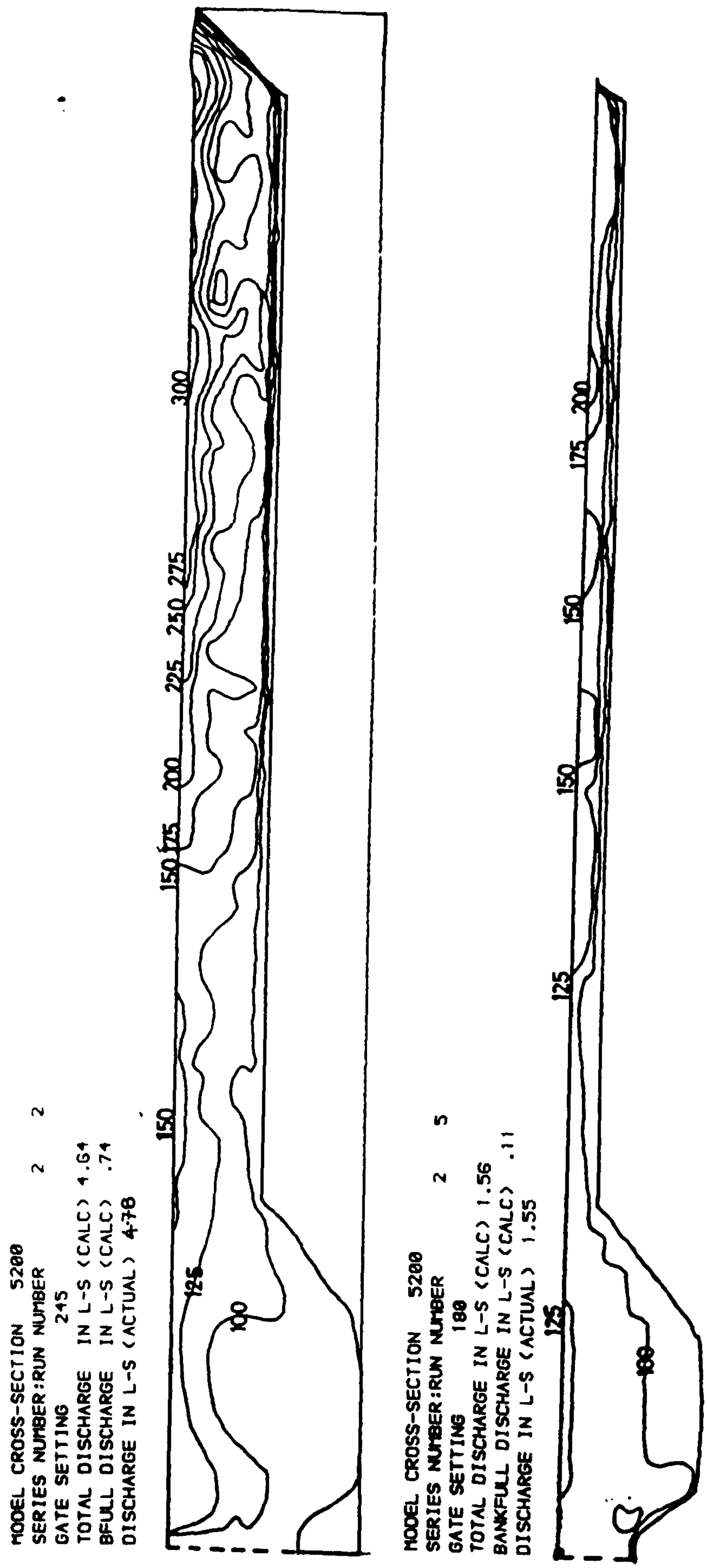


Figure 7.14
Isovel Plots Section 5200-Series 2-Runs 2 and 5
Normal Velocities in mm/s

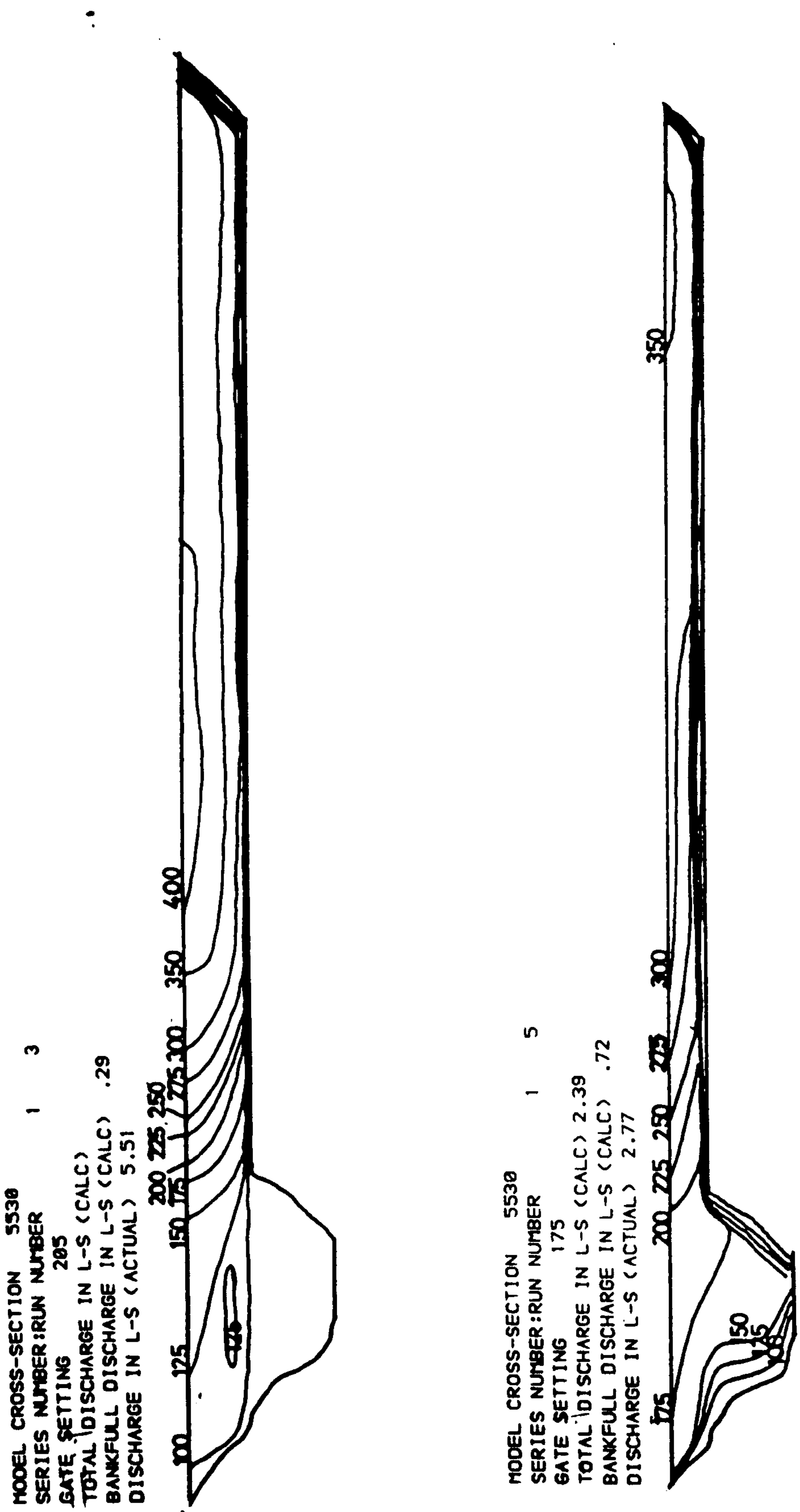


Figure 7.15
Isovel Plots Section 5530-Series 1-Runs 3 and 5
Normal Velocities in mm/s

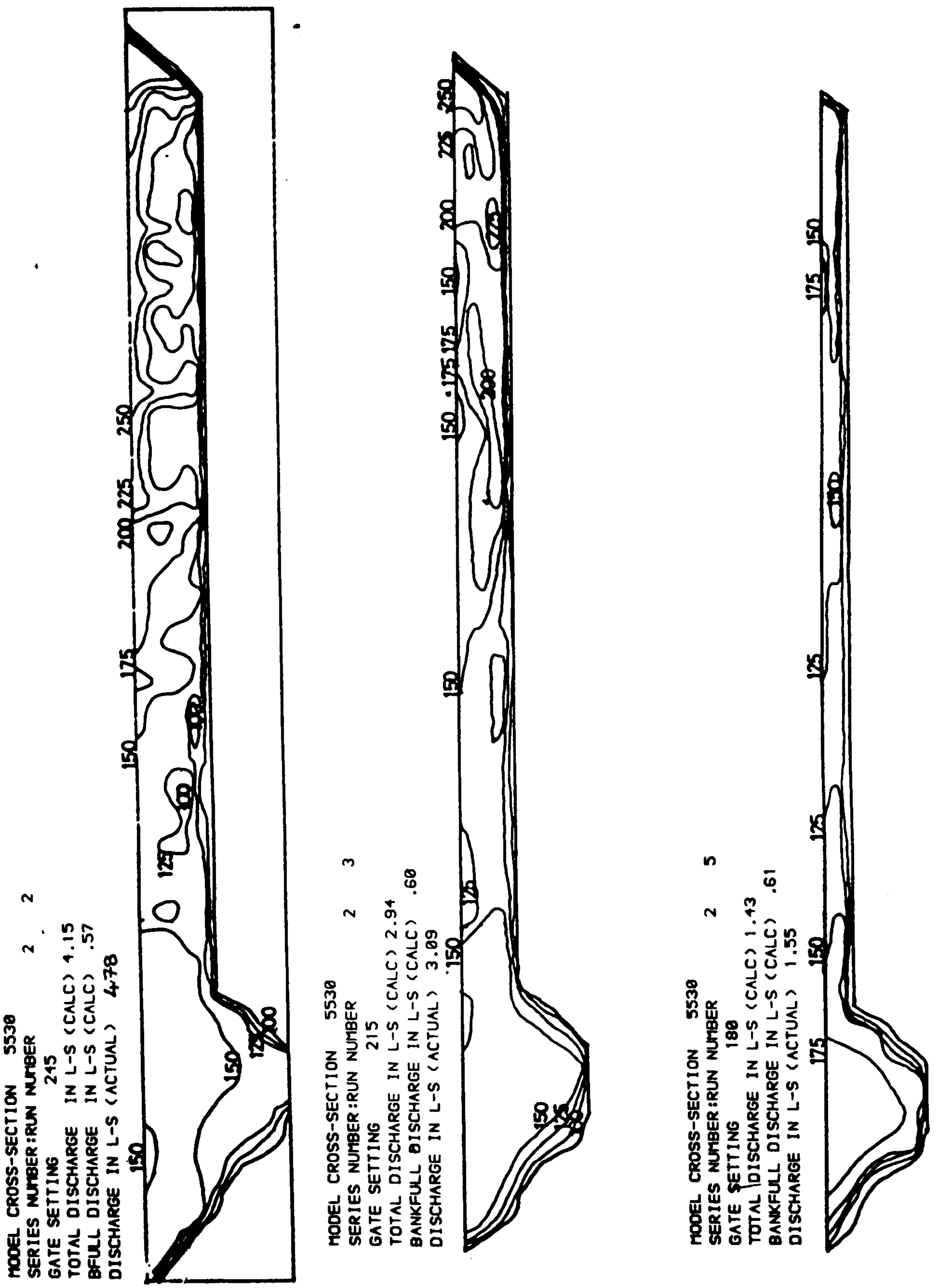


Figure 7.16
Isovel Plots Section 5530-Series 2-Runs 2,3 and 5
Normal Velocities in mm/s

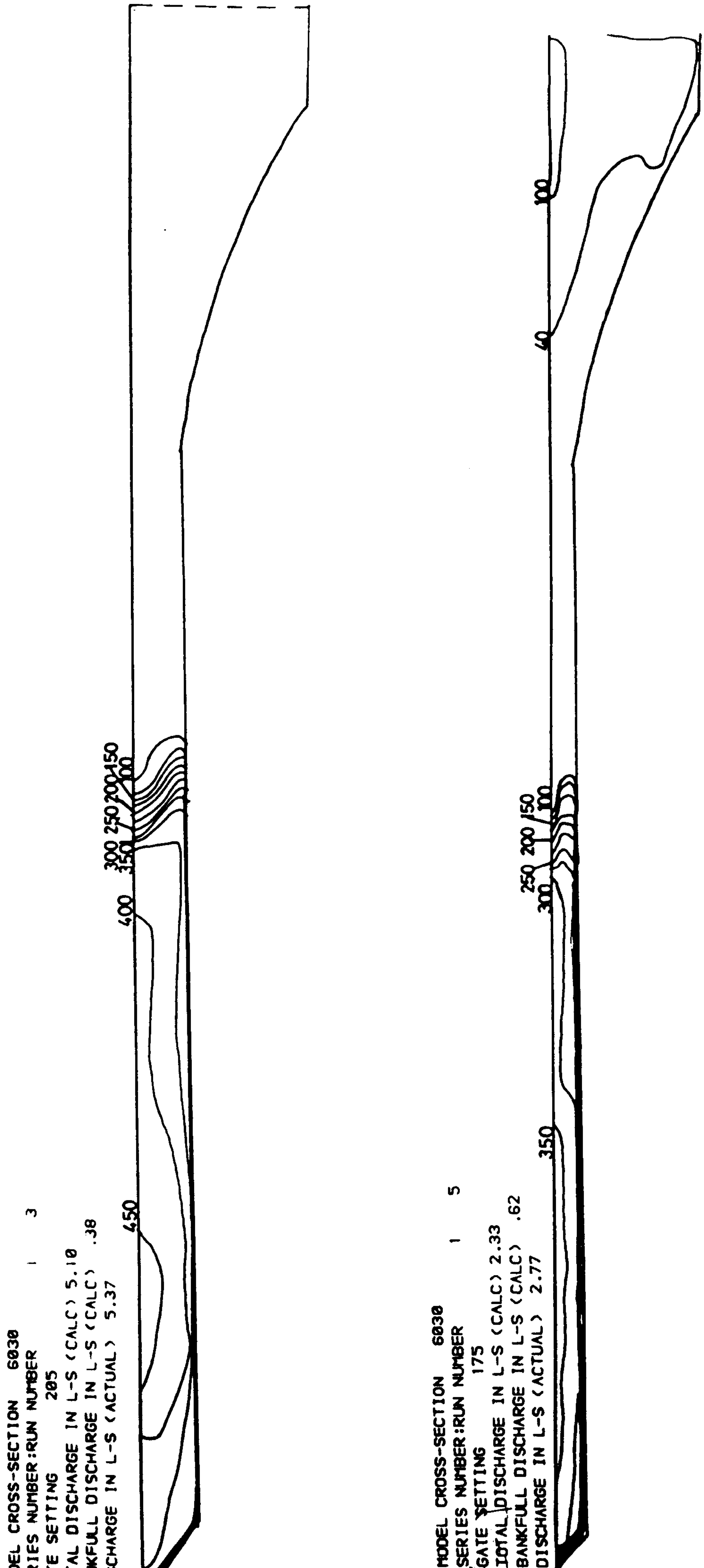


Figure 7.17
Isovel Plots Section 6030-Series 1-Runs 3 and 5
Normal Velocities in mm/s

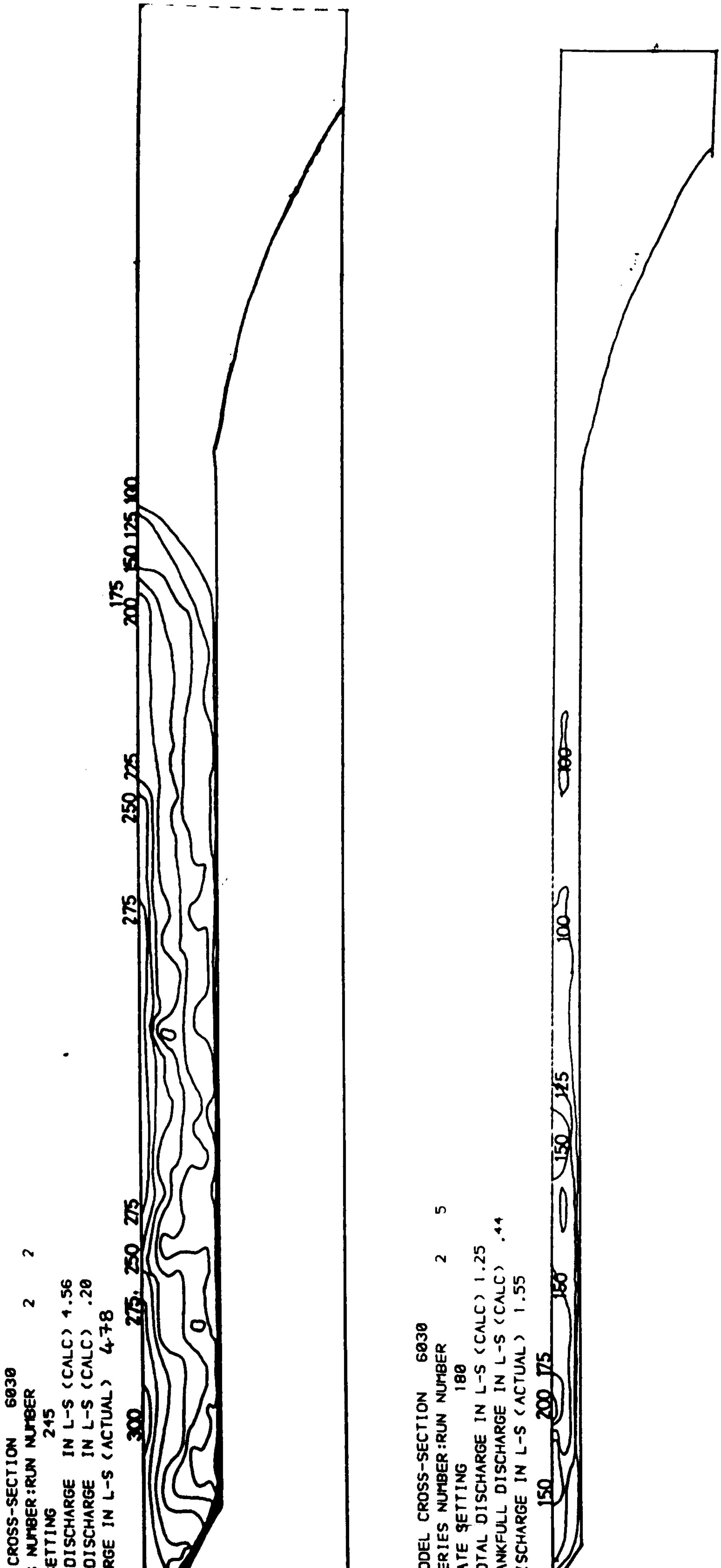


Figure 7.18
Isovel Plots Section 6030-Series 2-Runs 2 and 5
Normal Velocities in mm/s

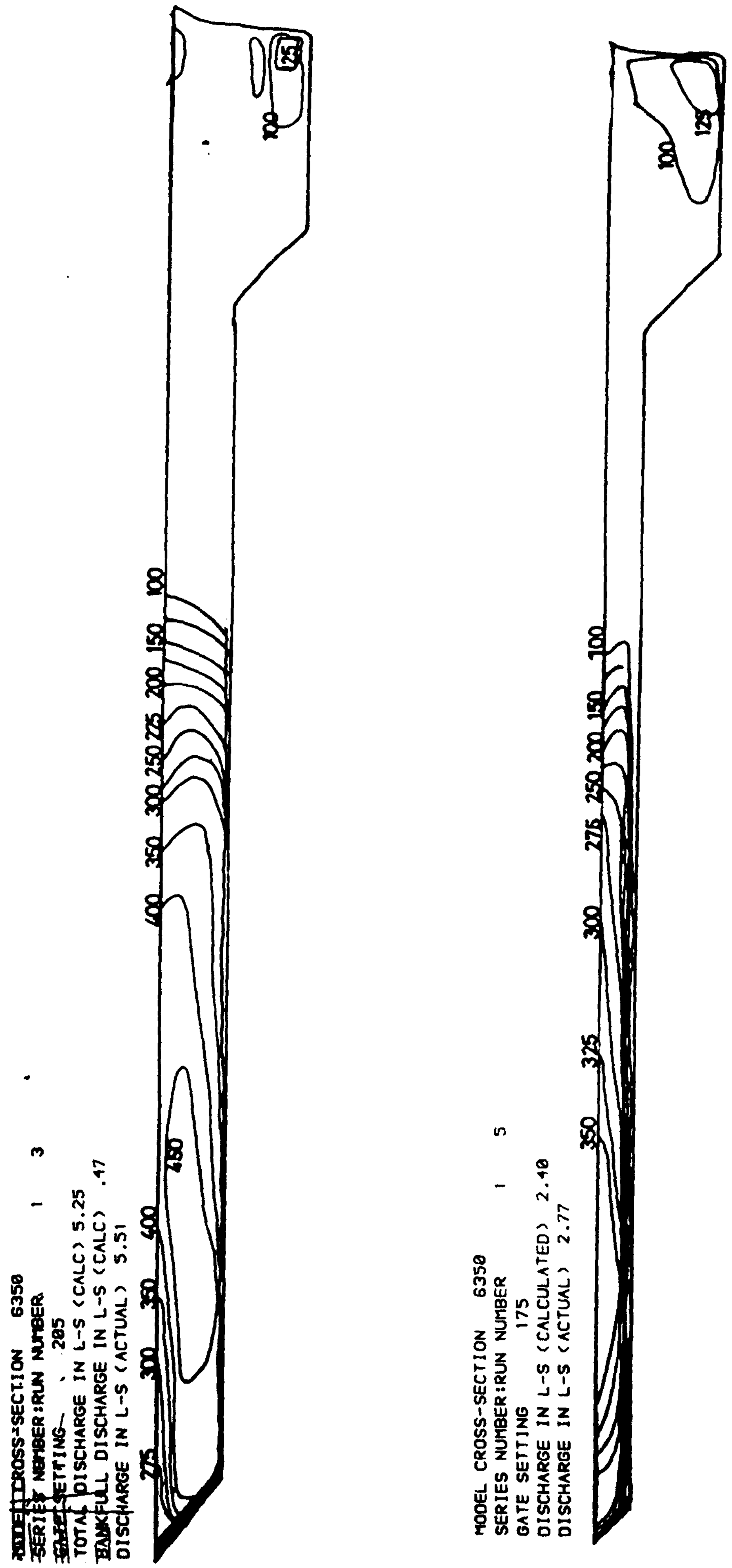


Figure 7.19
Isovel Plots Section 6350-Series 1-Runs 3 and 5
Normal Velocities in mm/s

main channel or floodplain, found by integrating the velocities over an area, were useful in gaining an insight to the contribution of the main channel in carrying food flows down the reach. Also floodplain roughness values have been calculated from the discharge it carried at each section.

Total discharges were calculated by integrating the velocities across the entire flow. These were compared with actual discharges in the model. Thus the reliability of the recorded data could be checked. The percentage error of calculated discharge over actual discharge at each section is given in the final column of table 7.1. Section Y=4730 produced the most reliable correlation between measured and calculated discharge, with discrepancies between the two ranging from 0% to 11% with an average error of 4% . Sections 5200, 5530, 6030 and 6350 produced less accurate data with average discrepancies of 7%, 8% 10% and 5% respectively. The reasons for the larger errors with these sections can most likely be attributed to their more complicated geometries. It seems reasonable to explain the discrepancies between the actual and measured discharges as primarily due to errors in boundary measurements and not the measured velocities. As a result, no velocity corrections were made for the isovel plots.

As mentioned above , it was possible to calculate the discharges on the floodplain and in the main channel at each section. The location of the boundaries between which the floodplain and main channel discharges were calculated can be found in figures 7.21 and 7.22., which show the cross-sections at which measurements were made. Roughness element heights on the floodplain for Series 2 and 12 have been included as well. Table 7.1 lists the main channel and floodplain discharges calculated from the isovel plots within the defined boundaries shown in figures 7.21 and 7.22 .

The floodplain Reynolds numbers were calculated and these ranged from 5000 to 41000, demonstrating that fully rough flow had been obtained on the floodplain for all discharges. This confirms the validity of the model based on Froudian similarity as it operated above the minimum established limit of Re=4000. See chapter 6 for details. Floodplain roughness values, for all the velocity profile runs, have also been calculated and are presented together with the Reynolds values, mean floodplain velocities and hydraulic radii in table 7.2 .

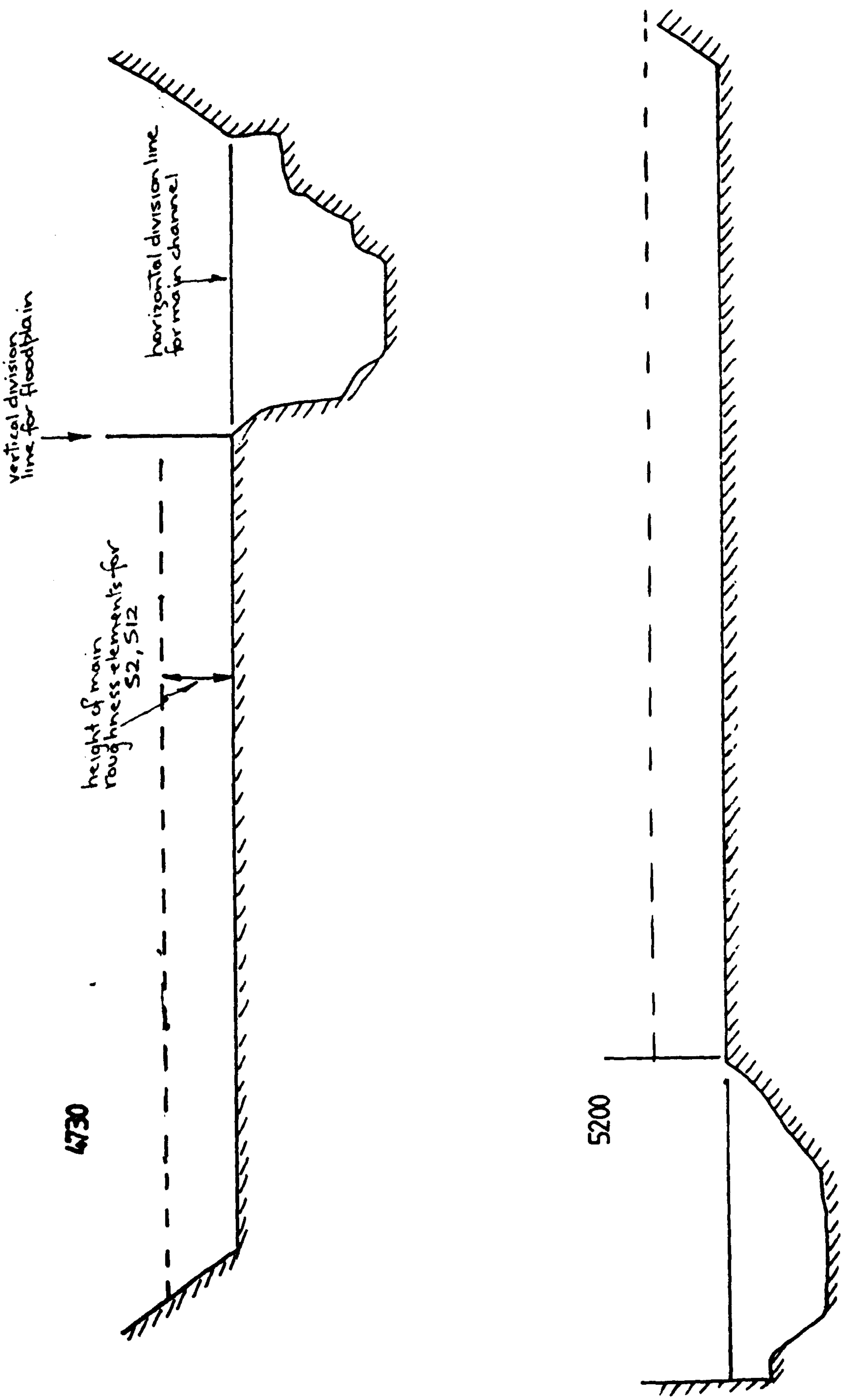


Figure 7.21
Profiles of Velocity Traverse Sections 4730 and 5200
Floodplain Roughness Heights and Division Lines for Floodplain
and Main Channel Discharge Calculation Included

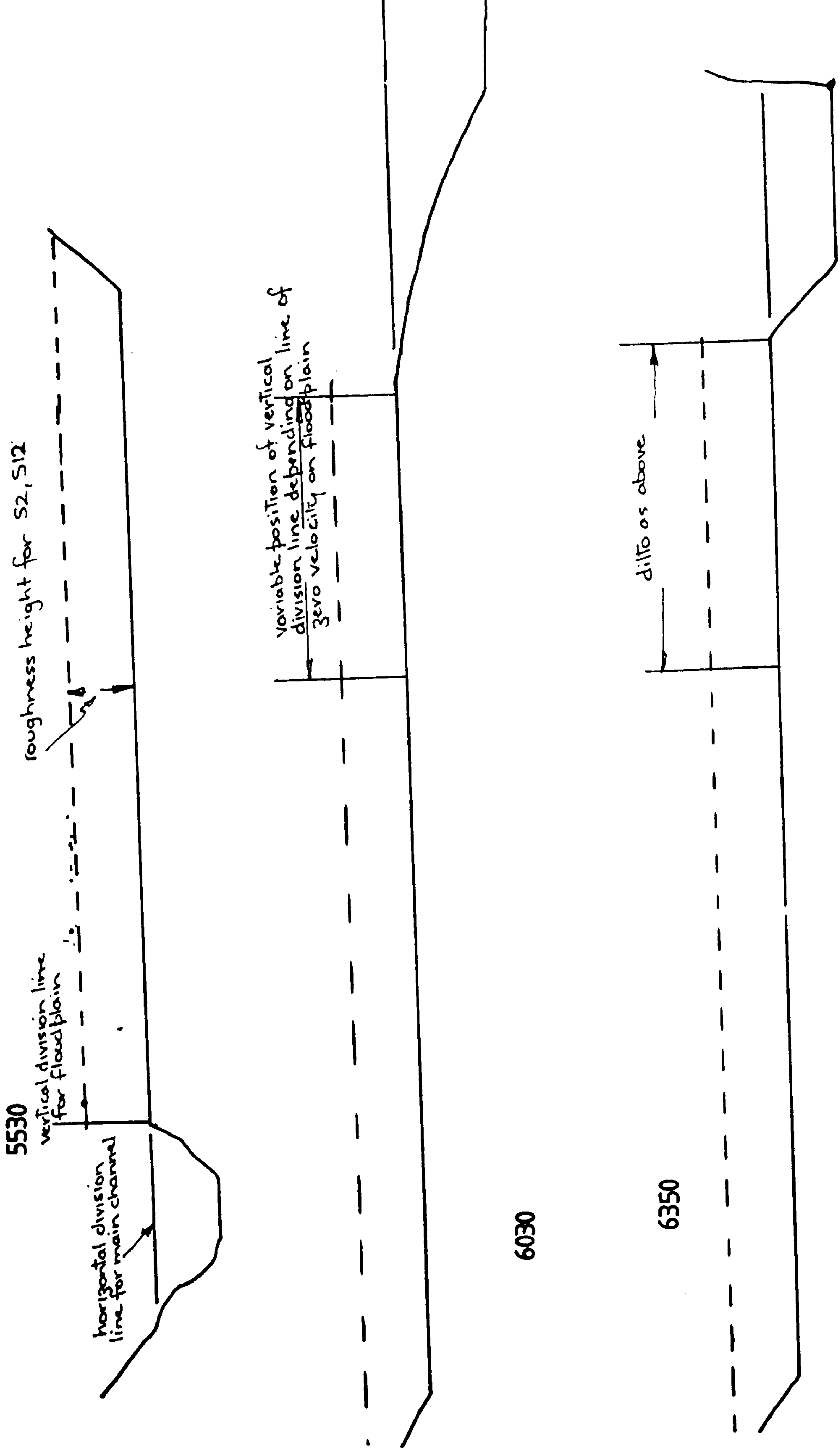


Figure 7.22
Profiles of Velocity Traverse Sections 5530,6030 and 6350
Floodplain Roughness Heights and Division Lines for Floodplain
and Main Channel Discharge Calculations Included

SECTION		CALCULATED FROM VELOCITY PROFILES Q_{TOT} (L/S) ①	$Q_{F/PLAIN}$ (L/S)	$Q_{MAIN\ CHANNEL}$ (L/S)	$P_{F/PLAIN}$ (CM)	$P_{MAIN\ CHANNEL}$ (CM)	$A_{F/PLAIN}$ (CM^2)	$A_{MAIN\ CHANNEL}$ (CM^2)	Q_{TOT} ACTUAL (L/S) ②	% error $\left[\frac{Q_{CALC}^{①} - Q_{ACT}^{②}}{Q_{ACT}^{①}}\right] \times 100$
4730	1.5	2.76	1.52	.97	44	25	72	-	2.70	+2
	1.6	1.36	.58	.66	41	-	41	-	1.51	-10
	2.1	8.88	5.87	1.18	54	-	280	-	8.78	+1
	2.2	4.95	2.71	1.21	49	-	177	-	4.78	+4
	2.3	3.27	1.45	1.14	47	-	136	-	3.10	+5
	2.4	2.34	.98	1.02	45	-	89	-	2.11	+11
	2.5	1.64	.57	.86	44	-	64	-	1.51	+9
	2.6	.68	0	.68	0	-	0	-	.70	-3
	12.1	8.99	6.42	.62	53	-	269	-	8.78	+2
	12.3	3.72	2.2	.85	46	-	136	-	3.65	+1
	13.3	3.25	2.09	.48	47	-	156	-	3.37	-4
	14.1	6.68	3.96	1.21	54	-	273	-	6.53	+2
	14.3	3.33	1.17	1.30	48	-	144	-	3.37	-1
5200	1.3	5.22	4.74	.10	55	20	153	60	5.37	-3
	1.5	2.70	1.94	.50	53	-	86	-	2.70	0
	1.6	1.08	.53	.41	50	-	46	-	1.51	-28
	2.2	4.64	3.63	.42	58	-	221	-	4.78	-3
	2.5	1.56	1.48	.11	51	-	87	-	1.51	+3
5530	1.3	4.80	3.95	.10	51	16	128	28	5.37	-11
	1.5	2.39	1.72	.35	47	-	72	-	2.70	-12
	2.2	4.15	3.10	.32	53	-	181	-	4.78	-13
	2.3	3.09	2.06	.34	50	-	134	-	3.10	0
	2.5	1.43	.77	.38	47	-	68	-	1.51	-5
6030	1.3	5.66	5.22	.24	48	20	124	75	5.38	+5
	1.5	2.33	1.84	.28	44	-	76	-	2.70	-14
	2.2	4.56	4.20	.20	66	-	230	-	4.78	-5
	2.5	1.25	.89	.26	38	-	65	-	1.51	-17
6350	1.3	5.25	4.25	.47	49	30	129	46	5.38	-2
	1.5	2.74	1.88	.40	46	-	76	-	2.70	+2
	2.2	4.29	3.98	.12	66	-	252	-	4.78	-10
	2.3	3.13	2.37	.40	63	-	184	-	3.10	+1
	2.5	1.69	1.01	.38	60	-	90	-	1.55	+9

Table 7.1
Discharge Data and Geometric Parameters Obtained from Velocity Traverses
Actual/Calculated Discharge Error

SECTION	SERIES-RUN	MEAN VELOCITY (M/S)	HYDRAULIC RADIUS (M)	REYNOLDS NO.	MANNING 'n'	$\lambda = 8gRS/V^2$	K_s (M)
4730	1.5	0.207	0.016	13517	0.018	0.099	0.006
	1.6	0.157	0.010	6282	0.017	0.105	0.004
	2.1	0.207	0.052	42991	0.039	0.313	0.098
	2.2	0.148	0.036	21362	0.042	0.428	0.092
	2.3	0.101	0.029	11698	0.054	0.734	0.112
	2.4	0.099	0.020	7854	0.042	0.520	0.059
	2.5	0.082	0.015	4771	0.042	0.560	0.046
	12.1	0.233	0.051	47321	0.034	0.242	0.072
	12.3	0.159	0.030	18770	0.035	0.304	0.054
	13.3	0.139	0.033	18443	0.043	0.445	0.087
	14.1	0.142	0.051	28674	0.055	0.651	0.180
	14.3	0.082	0.030	9867	0.067	1.149	0.152
5200	1.3	0.319	0.028	35463	0.017	0.071	0.005
	1.5	0.226	0.016	14641	0.016	0.083	0.004
	1.6	0.161	0.009	5928	0.016	0.092	0.003
	2.2	0.169	0.038	25789	0.038	0.345	0.079
	2.5	0.165	0.017	11235	0.023	0.163	0.014
5530	1.3	0.345	0.025	34659	0.014	0.055	0.003
	1.5	0.270	0.015	16536	0.013	0.054	0.001
	2.2	0.197	0.034	26947	0.031	0.227	0.045
	2.3	0.154	0.027	16533	0.033	0.292	0.047
	2.5	0.120	0.014	6919	0.029	0.262	0.022
6030	1.3	0.400	0.026	41348	0.013	0.042	0.001
	1.5	0.281	0.017	19383	0.014	0.057	0.002
	2.2	0.191	0.035	26682	0.032	0.246	0.051
	2.5	0.165	0.017	11317	0.023	0.162	0.014
6350	1.3	0.338	0.026	35552	0.015	0.060	0.003
	1.5	0.244	0.017	16109	0.015	0.072	0.003
	2.2	0.176	0.038	26876	0.037	0.319	0.074
	2.3	0.128	0.029	14903	0.043	0.465	0.080
	2.5	0.103	0.015	6175	0.034	0.367	0.033

Table 7.2
Reynolds Numbers, Roughness Parameters from Velocity Traverses

7.3 Flow Visualisation of Water Surface Velocities

Paths of surface streamlines for various flow conditions were visualised by photographing paper 'confetti' scattered on the water surface.The paper particles were illuminated with a stroboscope and photographed from a camera mounted on an enclosed frame placed over the flume. A 28mm wide-angle lense was used in the camera, mounted about 1.5 metres above the water surface. Time exposures between 4 and 10 seconds were used with a strobe flashing rate of 10 Hertz. Series 1,7 and 10 were photographed between Y=4700 and Y=6500. An example of the experiments is given in a photograph showing boundary separation at the bend between Y= 5500 and 6500. This observed flow separation, shown in figure 7.23, resulted in the decision to retain floodplain vegetation within these low flow zones, Series 11 and cut back the severest floodplain bends, Series 12, 13, and 14 . More photographs of surface flow have been left to chapter 8 for a fuller discussion.

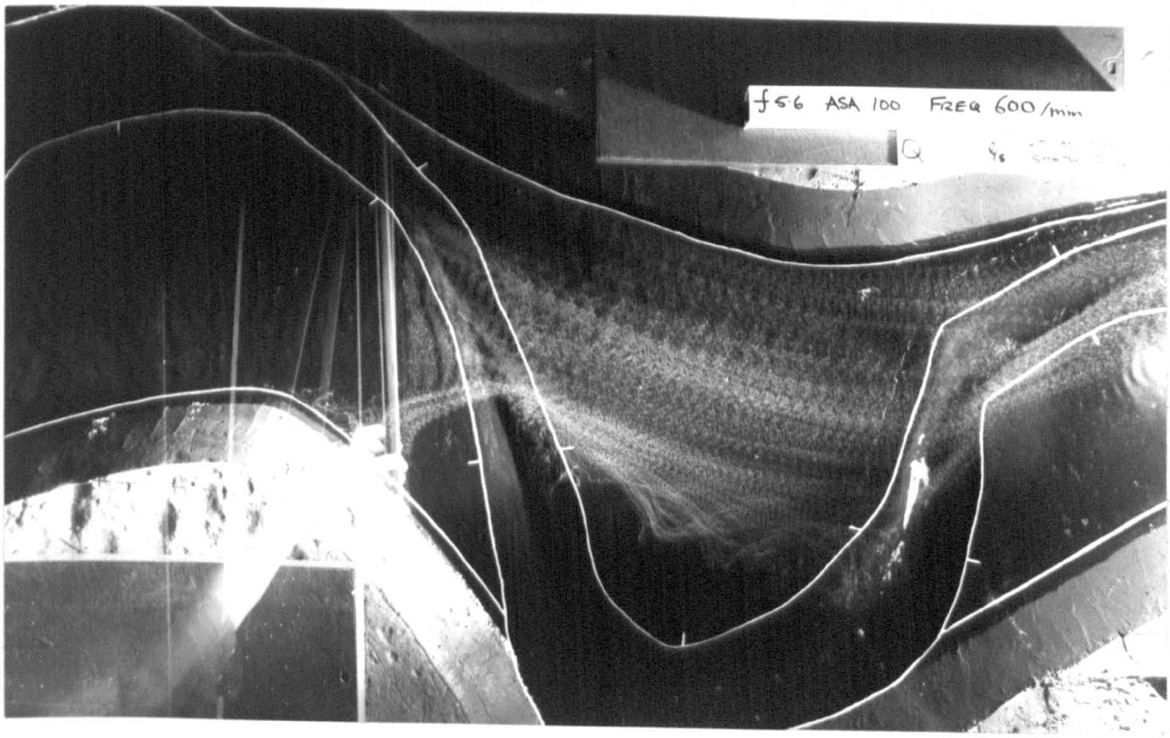


Figure 7.23
Photograph of Flow Separation at Floodplain Bend
Between Sections 5500 and 6500
Series 1, Discharge 1.96 l/s

NOTES ON ROUGHNESS TYPES

To simplify the presentation of the roughness type table various phrases have been used as shorthand:

FX- - the 'FX' series refers to various types of flexible strips punched out of sheets of acetate. A detailed description of them has been given in Appendix A.5 .

RR1 - enkamat matting, type 7720.

RR2 - 10mm dia. pebbles at 20mm centres.

RR3 - wire rods , 2.5 mm diameter of various lengths. Grid spacing is defined as 'lateral spacing' in mm by 'longitudinal spacing'in mm with the orientation along the flume. Given height is the length of wire above the floodplain surface.

marginal roughness - roughness positioned within area of floodplain adjacent to main channel approximately 40mm wide and running the length of the model on both floodplains where applicable.

reduced marginal roughness - as for marginal roughness but reduced to match river conditions for the 1985/1986 season when selective vegetation cropping took place.

side walls - boundary walls of floodplain.

Table 7.3
Roughness Key for Model Experiments

TABLE OF MODEL ROUGHNESS TYPES
IN MAIN CHANNEL

LABEL	DESCRIPTION
M1	painted cement render surface
M2	10mm dia. pebbles at 20mm centres
M3	horsehair matting filling channel
M4	RR1 plus glass spheres
M5	FX3 plus glass spheres
M6	FX5 plus glass spheres

Table 7.3 (Continued)

LIST OF MODEL ROUGHNESS TYPES
ON FLOODPLAIN

LABEL	DESCRIPTION
F1	gloss painted polystyrene surface
F2	FX1
F3	RR2
F4	FX3 on top of RR2 marginal FX7
F5	FX3 marginal FX7
F6	FX3 FX4 up side walls
F7	FX3 plus RR3 at 40mm by 100mm grid, non-submerged FX4 up side walls
F8	FX1 plus RR3 at 40mm by 70mm grid, non-submerged. FX4 up side walls
F9	FX1 plus RR3 at 40mm by 70mm grid, non-submerged FX6 up side walls
F10	RR3 at 40mm by 35mm grid, non-submerged FX6 up side walls
F11	RR3 at 40mm by 35mm grid, non-submerged marginal RR3 at 25mm by 35mm grid, non-submerged FX6 up side walls
F12	RR3 at 40mm by 35mm grid, 40mm height marginal RR3, 25mm by 35mm grid, non-submerged FX6 up side walls
F13	RR3 at 40mm by 35mm grid, 30mm height reduced marginal RR3, 25mm by 35mm grid, non-submerged FX6 up side walls
F14	RR3 at 40mm by 35mm grid, 30mm height reduced marginal RR3, 25mm by 35mm grid, non-submerged
F15	RR3 at 40mm by 35mm grid, 30mm height reduced marginal roughness RR3, 25mm by 35mm grid, 30mm height
F16	RR3 at 40mm by 35mm grid, 30mm height marginal roughness RR3, 25mm by 35mm grid, non-submerged
F17	RR3 at 40mm by 35mm grid, 30mm height marginal roughness RR3, 25mm by 35mm grid, non-submerged RR3 at 40mm by 35mm grid, non-submerged at selected bends

Table 7.3 (Continued)

CHAPTER 8

Analysis

This chapter tackles the problems listed below using data from chapters 5 and 7. Analysis and discussion have been presented and, where relevant, solutions have been proposed.

1. Maintenance of the River Roding Flood Alleviation Scheme with due regard being given to maximising its discharge capacity whilst minimising annual vegetation clearance, to reduce costs and preserve the ecological environment.

2. The interaction between a meandering main channel and floodplain and its effect on the total carrying capacity of the compound river.

3. Predicting the discharge characteristics of a compound channel consisting of a meandering main channel within a vegetatively roughened floodplain.

8.1 Depth Discharge Curves - Comparisons

Depth-discharge data from the field studies have already been used to prove the laboratory model and further use of them is unnecessary here, except to provide a comparison with Series 7 and Series 8. The analysis of the depth-discharge curves from the model has been aimed at finding practical solutions to the problem of the management of a stretch of compound river such as the River Roding Flood Alleviation Scheme. Data have been drawn from chapters 6 and 7.

8.1.1 Model Data

In this chapter, the model Series will be referred to in an abbreviated form, e.g. S7 will represent Series 7. All model data have been scaled up to the equivalent prototype values to enable the results of any analysis here to be meaningfully assessed.

To assist in a numerical evaluation of the stage-discharge curves, Series 7 to 14 were fitted with 3rd order polynomial functions. Curve fitting was applied using a numerical analysis package incorporated into a Fortran programme written by the author.

The NAG curve fitting routine, using a numerical method of the Tchebycheff approximation, calculates a minimax polynomial fit to a set of data points.

Table 8.3 at the end of the chapter gives the polynomial constants calculated for each set of data points from Series 7 to 14.

Curve fitting was applied to the overbank portions of the stage-discharge curves to prevent an overall misfit due to the sudden change in curve slope at bankfull level. Good curve fits were obtained for all the data. Figures 8.1, 8.2 and 8.3 are plots of Series 7 to 14 with the best fit curves superimposed. Cross-over of the curves occurs in some instances at low depth values when in reality they should fall on the same line. The effect of this when comparing some sets of data, using the curves, has produced grossly incorrect results at low depths. These have been discounted and as will be seen , have been included in the comparison plots but only as dotted lines.

Comparisons of plots entailed first of all choosing a 'reference' curve against which other curves could be compared. Then the chosen 'reference' curve was subtracted from the curve being considered and the result replotted.

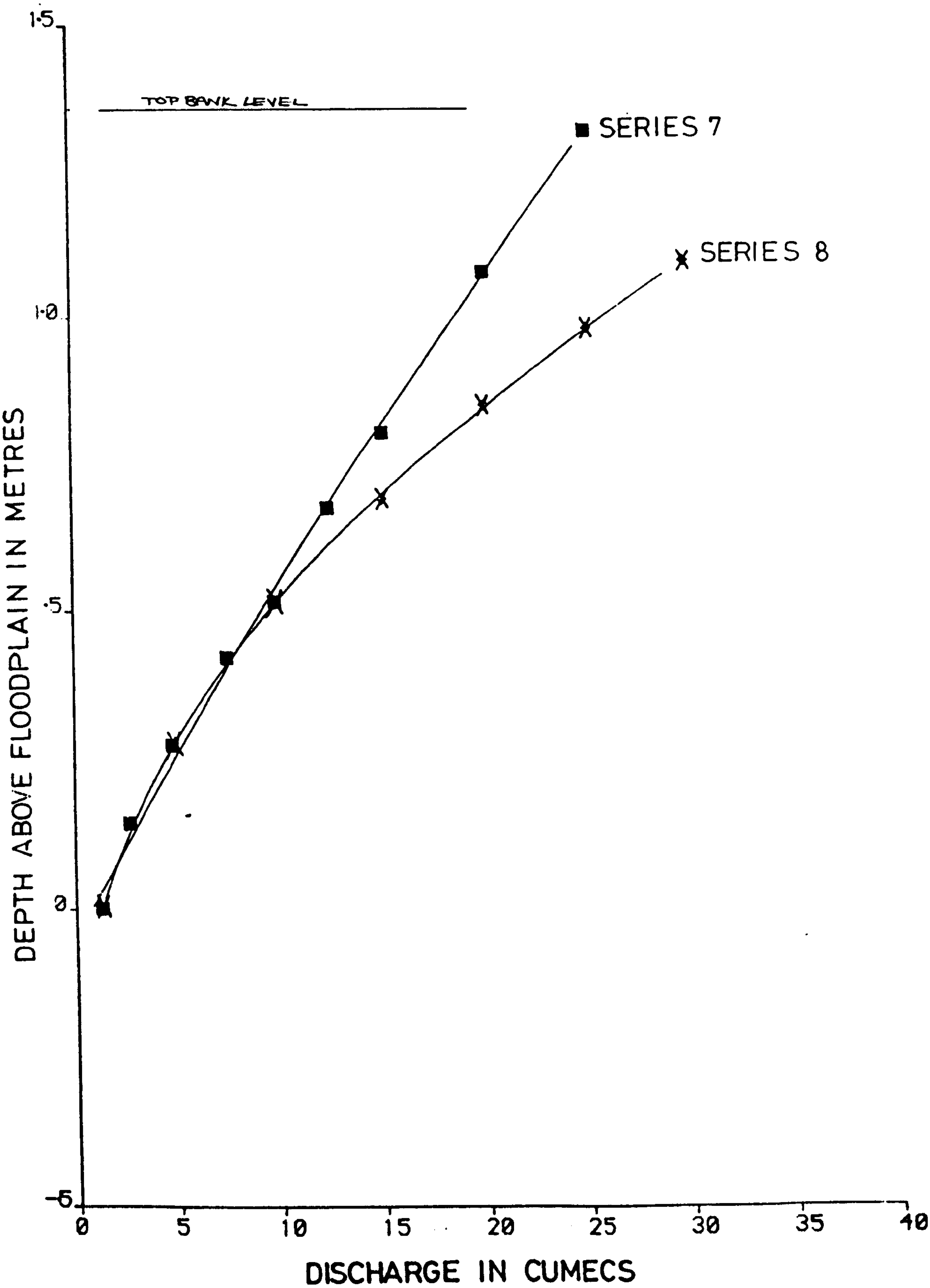


Figure 8.1
Plot of Scaled Model Depth-Discharge Data with Fitted Curve
Series 7 and 8

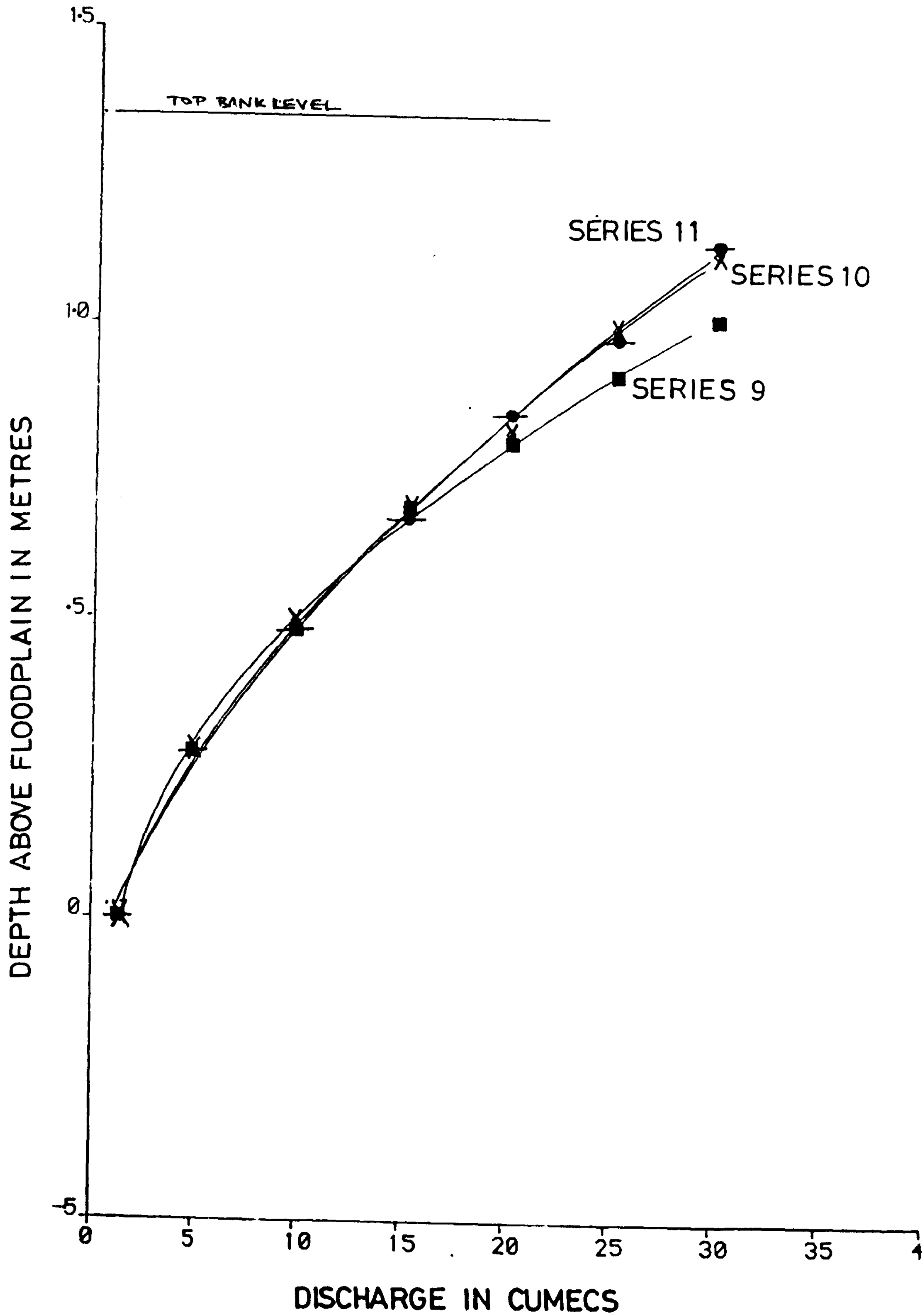


Figure 8.2
Plot of Scaled Model Depth-Discharge Data with Fitted Curve
Series 9,10 and 11

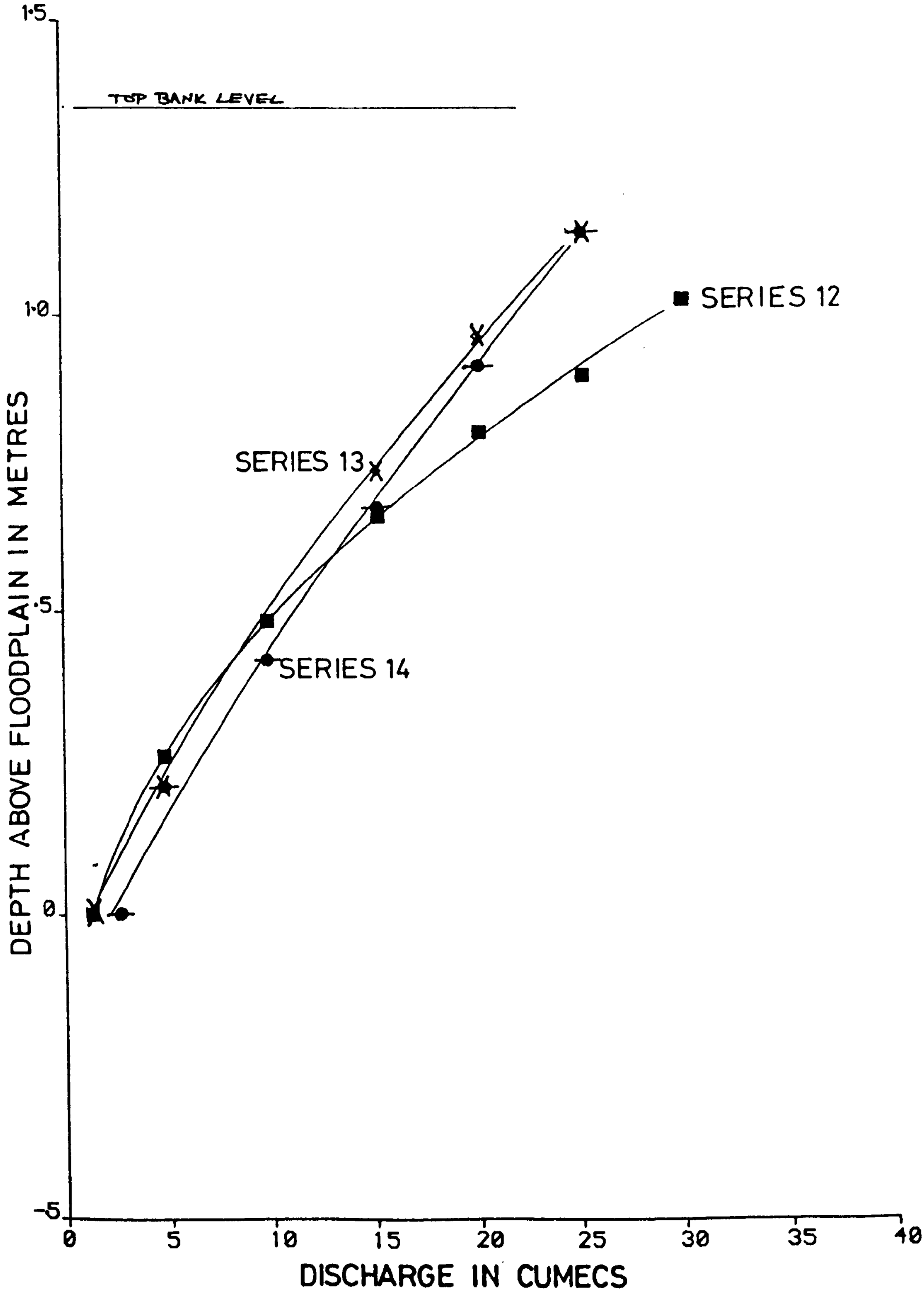


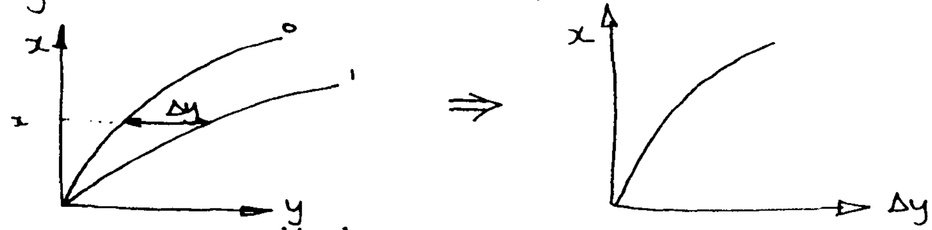
Figure 8.3
Plot of Scaled Model Depth-Discharge Data with Fitted Curve
Series 12,13 and 14

This method of comparison is explained here:

$y_1 = a_1 + b_1 x_1 + c_1 x_1^2$ polynomial (1)

$y_0 = a_0 + b_0 x_0 + c_0 x_1^2$ reference polynomial

$$\Delta y = y_1 - y_0 = (a_1 - a_0) + (b_1 - b_0) x_1 + (c_1 - c_0) x_1^2$$



y - represents discharge

x - represents depth of flow

Therefore, to plot Δy as a function of x, subtract the polynomial coefficients as shown above and re-plot the new curve with the modified coefficients.

Two types of comparison have been made. The first was the difference in discharge between the two curves, for a given depth above the floodplain, and the second was the percentage change in discharge. Five sets of plots have been produced, the first of which is S8 compared with S7, two plots of which are given in Figures 8.4 and 8.5.

The dotted portion of the line in figure 8.5 is an obviously meaningless result and has been included only for completeness. In figure 8.4, however, the effect of the curve fitting error is not significant. Taking S7 and S8 as equivalent to the prototype data produced in chapter 5, for the '84/'85 and '85/'86 wet seasons on

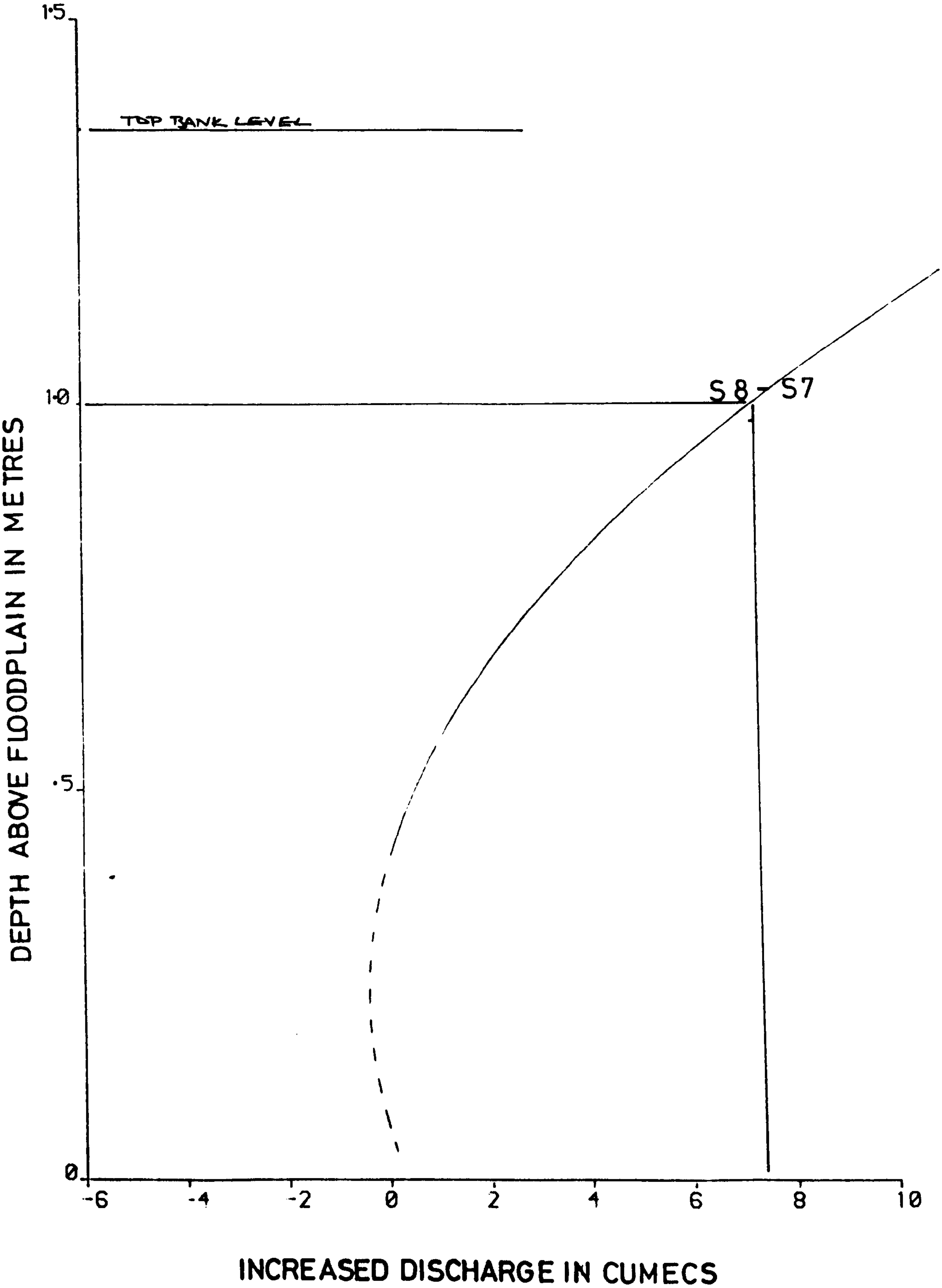


Figure 8.4
Plot of Discharge Difference Between Series 8 and Series 7 Using the Fitted Curves

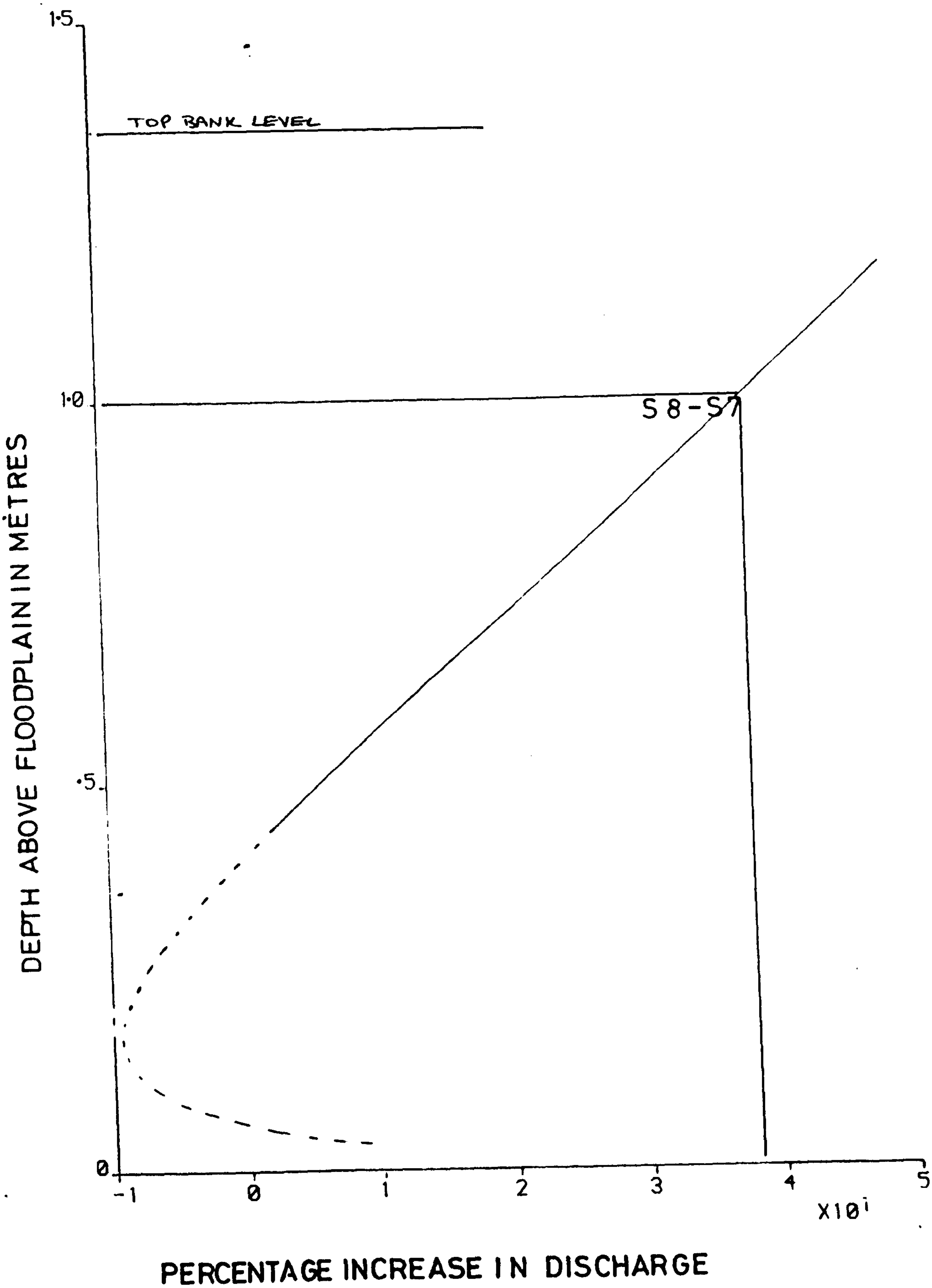


Figure 8.5
Plot of Percentage Discharge Difference Between Series 8 and Series 7 Using the Fitted Curves

the river, (see figure 8.6 for a comparison of the best-fit curves between the river data over the two seasons and S7 and S8) the improvement in discharge from clearing the floodplain between the two seasons is very marked. At a flow depth of 1 metre above the floodplain level the increase in discharge, taken from figure 8.4, is about 7.5 cumecs and this represents, from figure 8.5, an increase of almost 40% . Data from the figures cannot be inferred much above an overbank flow depth of 1 metre due to the lack of prototype data for S7 at high discharges .

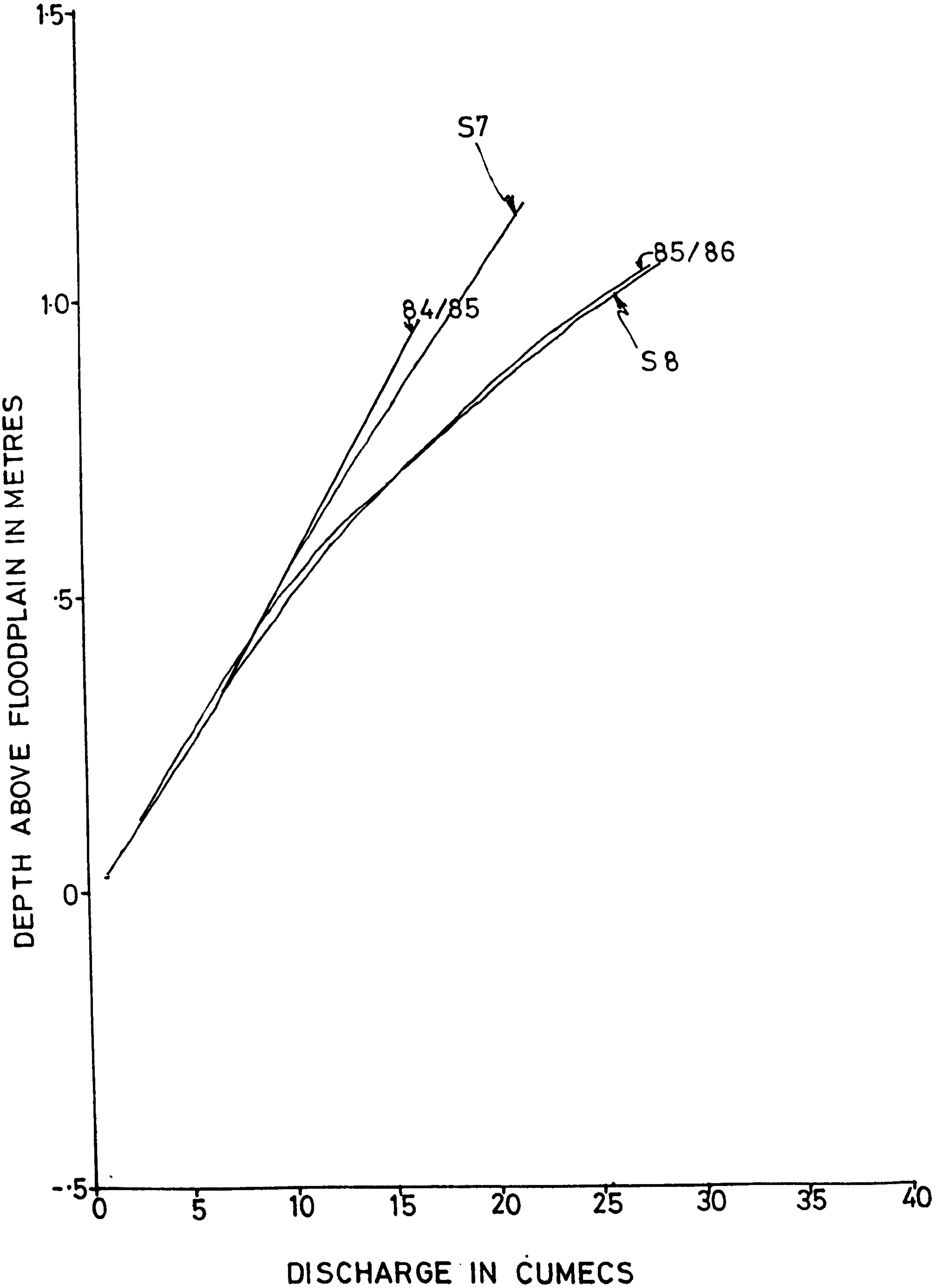


Figure 8.6
Comparison of River Data with S7 and S8
Using the Fitted Curves for each set of Data Points

Having evaluated the improvement in discharge capacity between S7 and S8, the modelled prototype roughness states, the following presentation deals with the improvements resulting from the schemes outlined in chapter 7, using S7 or S8 as a reference curve. S9, S10 and S11 were similar to S8 and therefore the latter was chosen as a basis for comparison. The following roughness descriptions of S9 to S11 relate to their prototype equivalent:

S9 - completely cleared floodplain, no marginal vegetation and main channel uncleared.

S10 - cleared floodplain with the exception of a 2 metre margin of reeds remaining adjacent to the main channel banks, main channel uncleared

S11 - as for S10 with the addition of uncleared areas inside the floodplain bends (see figure 7.2)

Figures 8.7 and 8.8 are graphical presentations of the results, S11-S8, S10-S8, S9-S8 . As already mentioned, the dotted portions of the curves are meaningless and nothing can be inferred from them. The changes in discharges of all the curves compared with S8 are relatively small. S9 exhibited an increase in discharge over S8 (at a floodplain flow depth of 1 metre) of about 3 cumecs or just over 10%. S10 and S11 differed little from S8.

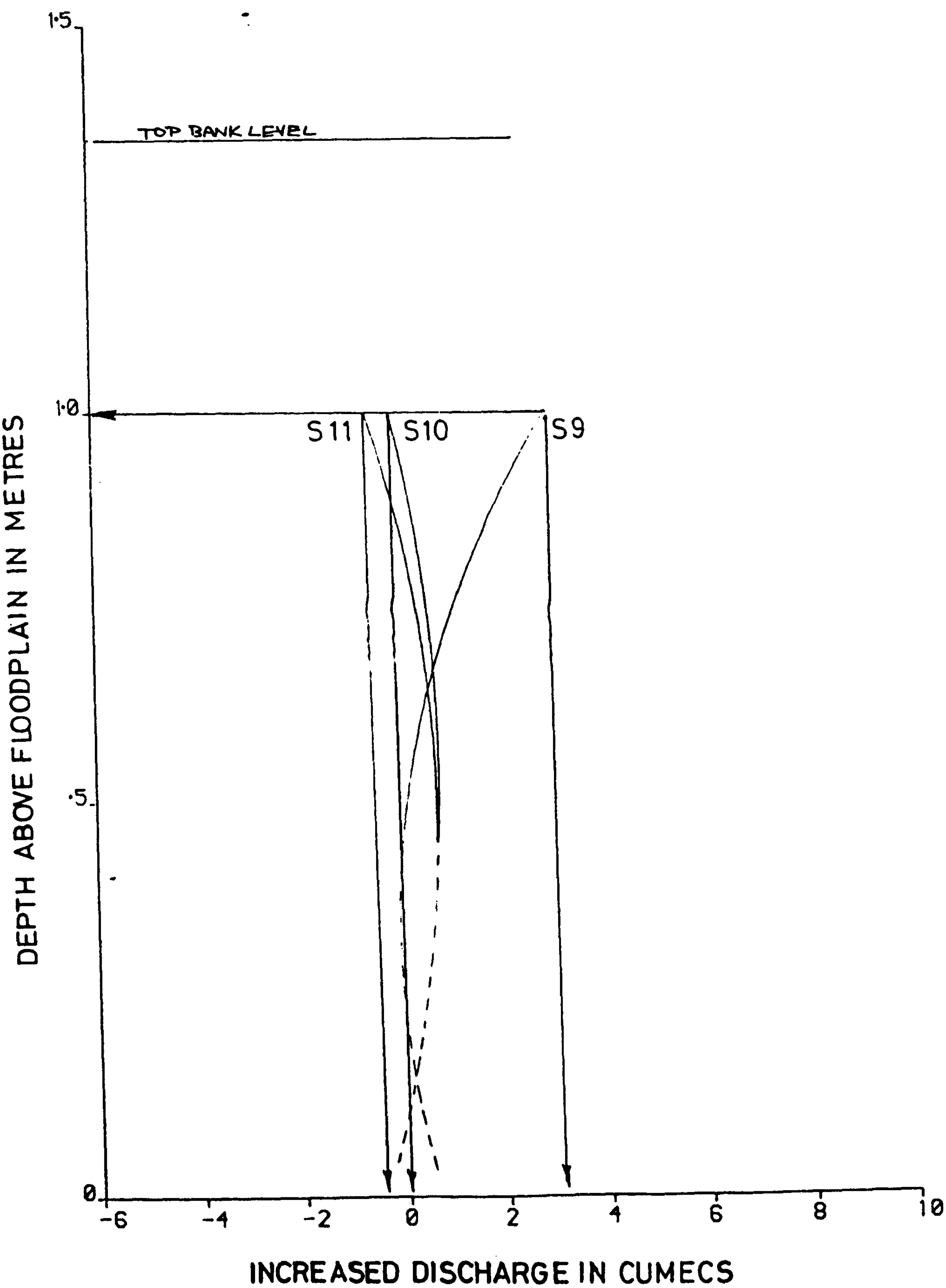


Figure 8.7
Plots of Discharge Differences for S9, S10 and S11 Compared with S8 Using Fitted Curves

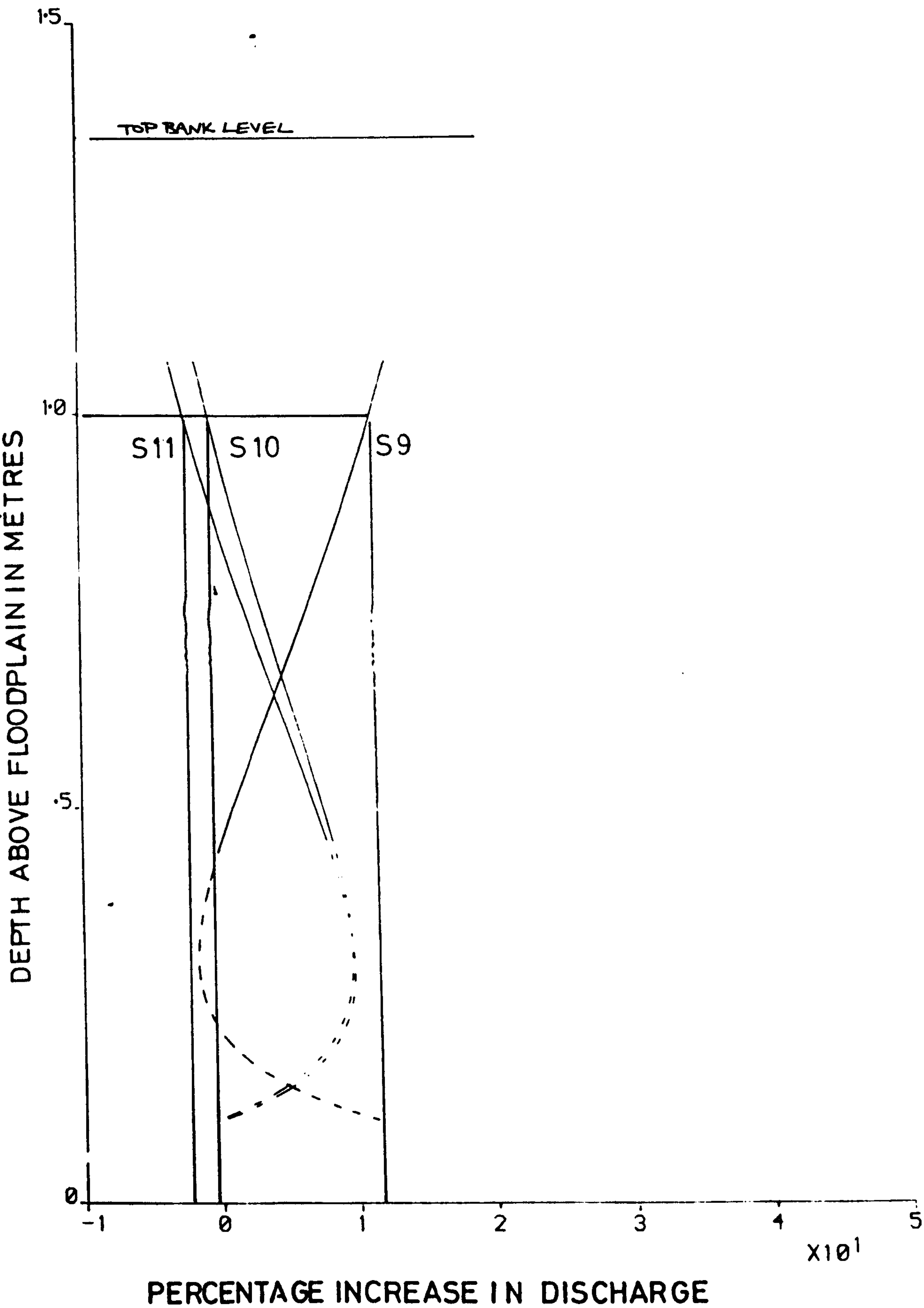


Figure 8.8
Plots of Percentage Discharge Difference for S9, S10 and S11 Compared with S8 Using Fitted Curves

S12, S13 and S14 were grouped together because the boundaries of the floodplain were altered from S12 onwards. As already described in chapter 7, two severe floodplain bends were cut back along the modelled stretch, with maximum localised floodplain widths increased by 25% and 40% . The increase in plan area of the floodplain was less than 5% . (see figure 7.3). S12, S13 and S14 have been compared with the rougher prototype case of S7 and possess the following equivalent prototype surface roughnesses:

S12 - as for S11 - cleared floodplain with the exception of a 2 metre margin of reeds remaining adjacent to the main channel banks, main channel uncleared.

S13 - as for S7 - no vegetation clearance on the floodplain,main channel uncleared

S14 - as for S13 , but main channel cleared

Figures 8.9 and 8.10 are graphical presentations of the curves S14-S7, S13-S7, S12-S7. At a floodplain flow depth of 1 metre, S12, as expected, exhibited a significant improvement in discharge capacity over S7, about 10 cumecs or 55% increase. S13, a simulation of no floodplain maintenance, resulted in an increased discharge in the reach of nearly 3 cumecs or 15% and S14,possessing the same surface roughness as S13 but with the main channel cleared, exhibited an increase of 3.5 cumecs or 20% over S7. As the bankfull roughness of the channel, if it were to be dredged, is not known, this figure might not necessarily represent the increase to be found from carrying out such an exercise.

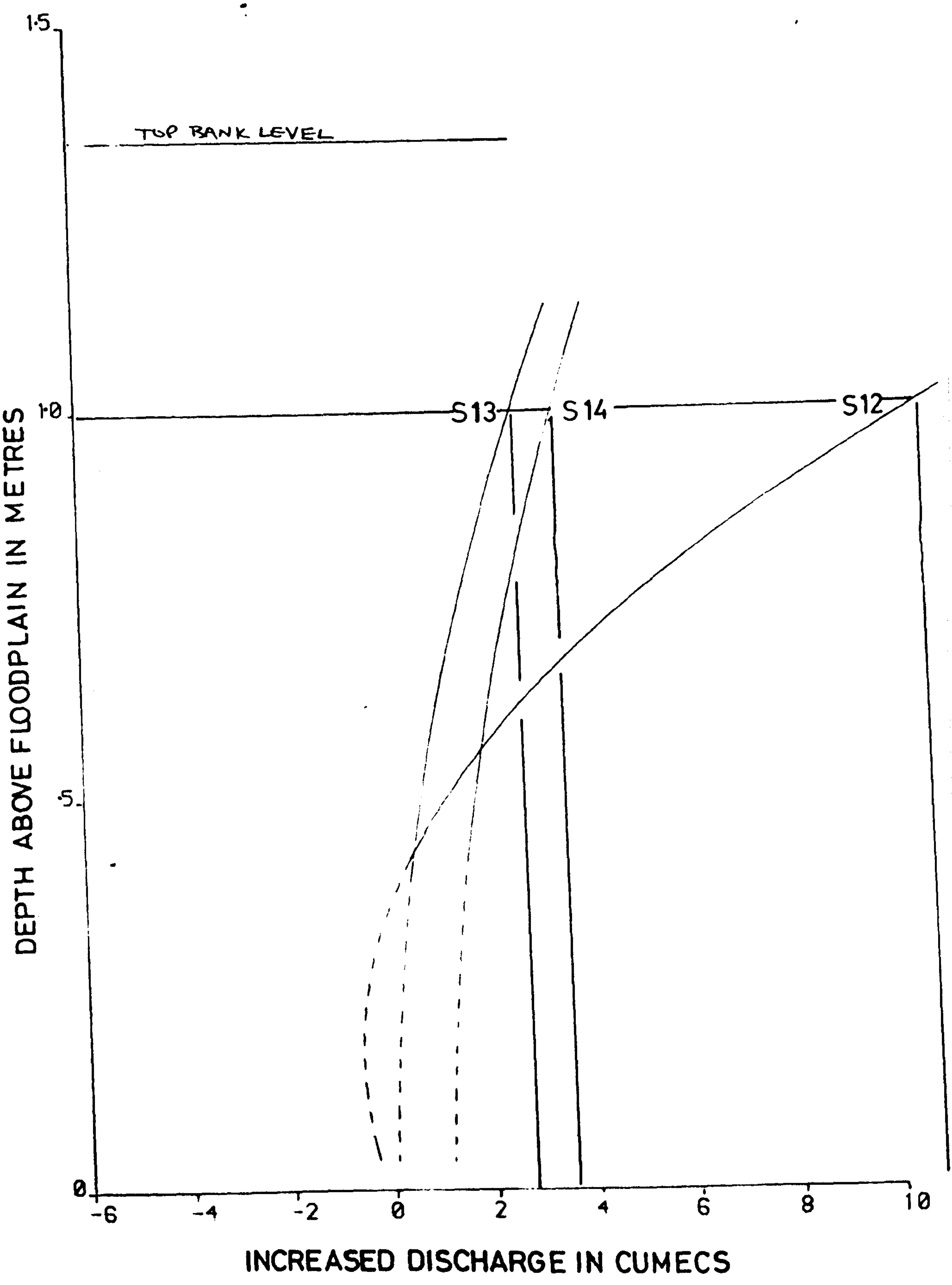


Figure 8.9
Plots of Discharge Differences for S12, S13 and S14 Compared with S7 Using Fitted Curves

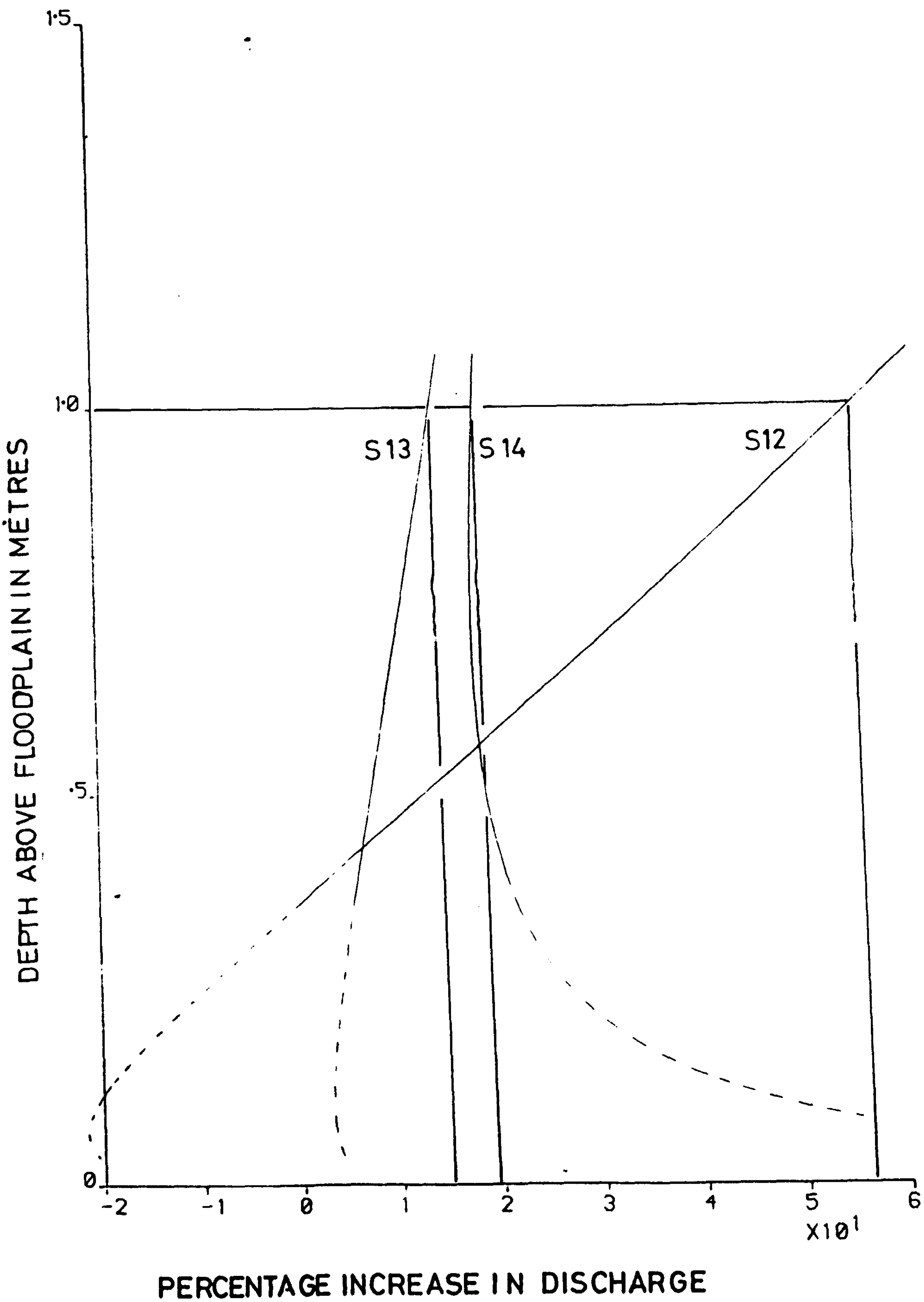


Figure 8.10
Plots of Percentage Discharge Differences for S12,S13 and S14
Compared with S7 Using Fitted Curves

The two groups of curves provide some comparisons between different surface roughness states in the river but no assessment has been made of the effect of reducing the shape roughness of the floodplain. Two comparisons have been produced from the available data, S12-S11 and S13-S7. Both sets of Series have the same surface roughness but different floodplain form roughness. Figure 8.11 and 8.12 are plots of S12 relative to S11 and figures 8.13 and 8.14, are plots of S13 relative to S7.

At a flow depth of 1 metre, the reduced severity of floodplain meandering has increased the capacity of the reach by 4 cumecs or 16% with the roughness on the floodplain corresponding to that produced from the proposed policy of minimum maintenance, S11. For the same inundation, and maximum vegetative roughness on the floodplain, S13, capacity was increased by 2.5 cumecs or 14%.

8.1.2 Conclusions

It is worth concluding this section with a presentation of the most important facts that the above analysis has revealed.

1. The difference in discharge capacity of the reach between no maintenance of the floodplain, S7, and a policy of minimum clearance, S11, (2 metre margin of reeds and selected vegetation remaining uncut on the outside of floodplain bends) is significant. At a floodplain flow depth of 1 metre, an increase in discharge of 7.5 cumecs, or nearly 40%, was found.

2. The effect of the proposed minimal clearance policy of the floodplain vegetation, S11, leaving substantial stands of vegetation

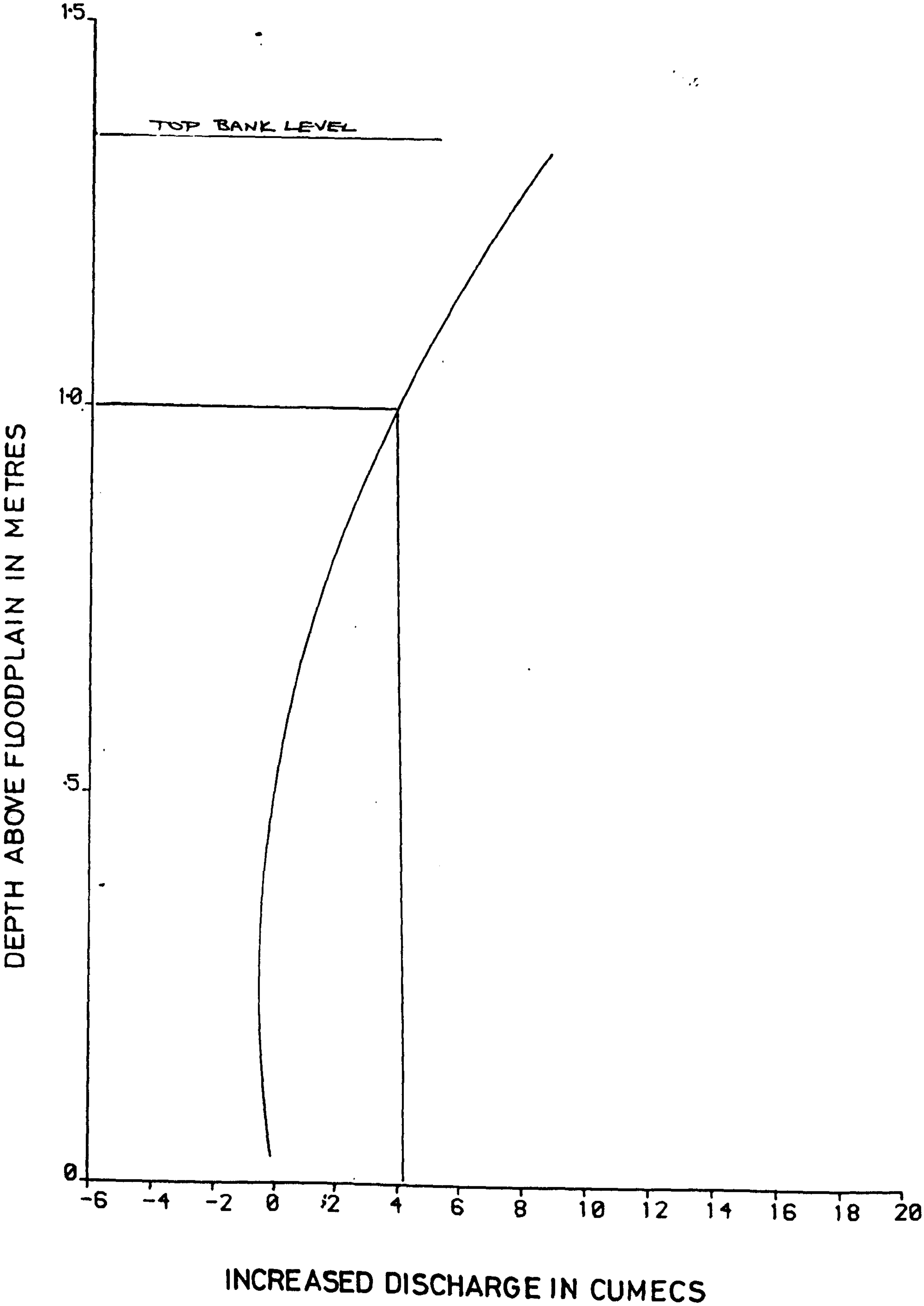


Figure 8.11
Plot of Discharge Difference Between S12 and S11
Using Fitted Curves

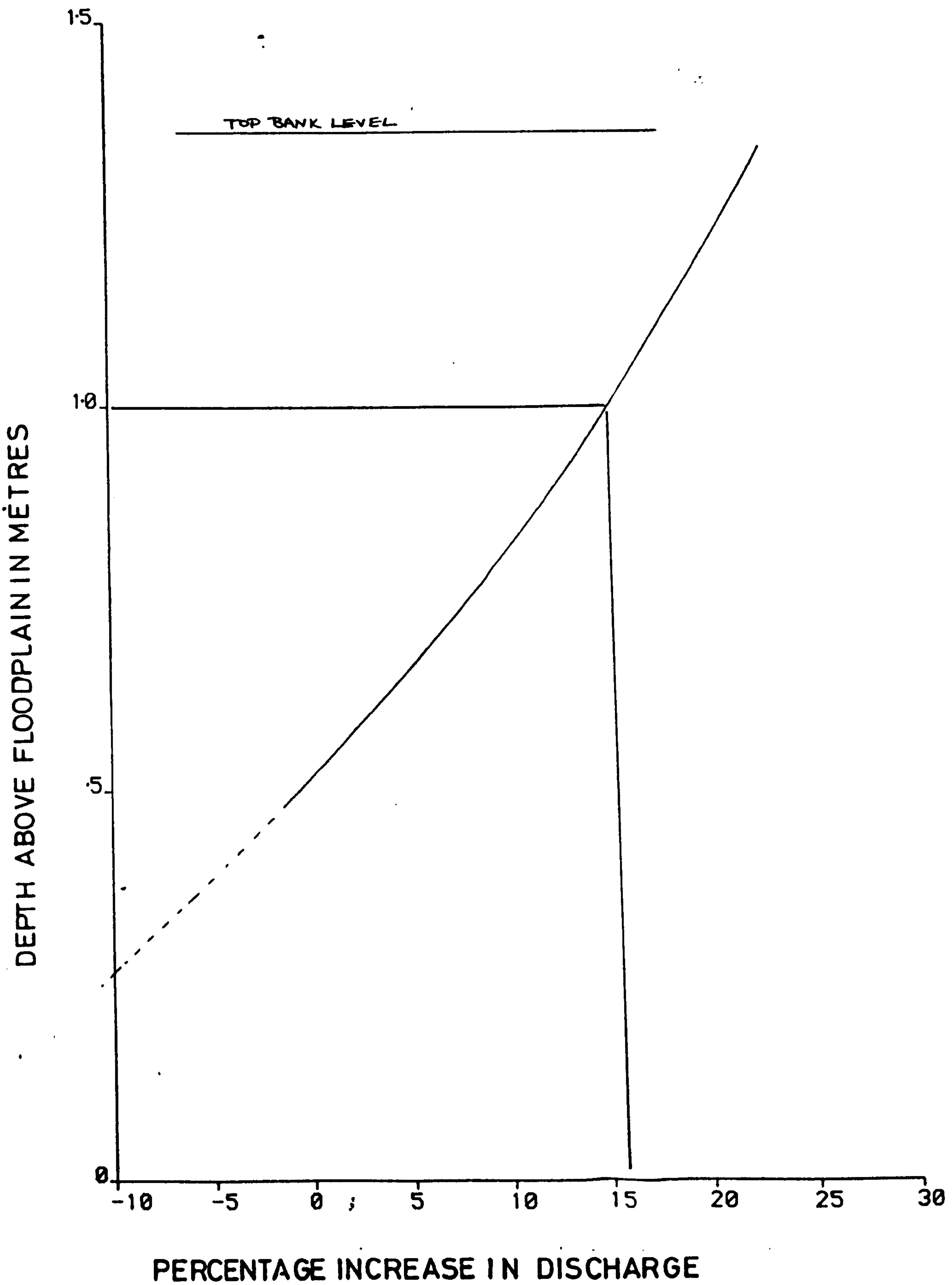


Figure 8.12
Plot of Percentage Discharge Difference Between S12 and S11 Using Fitted Curves

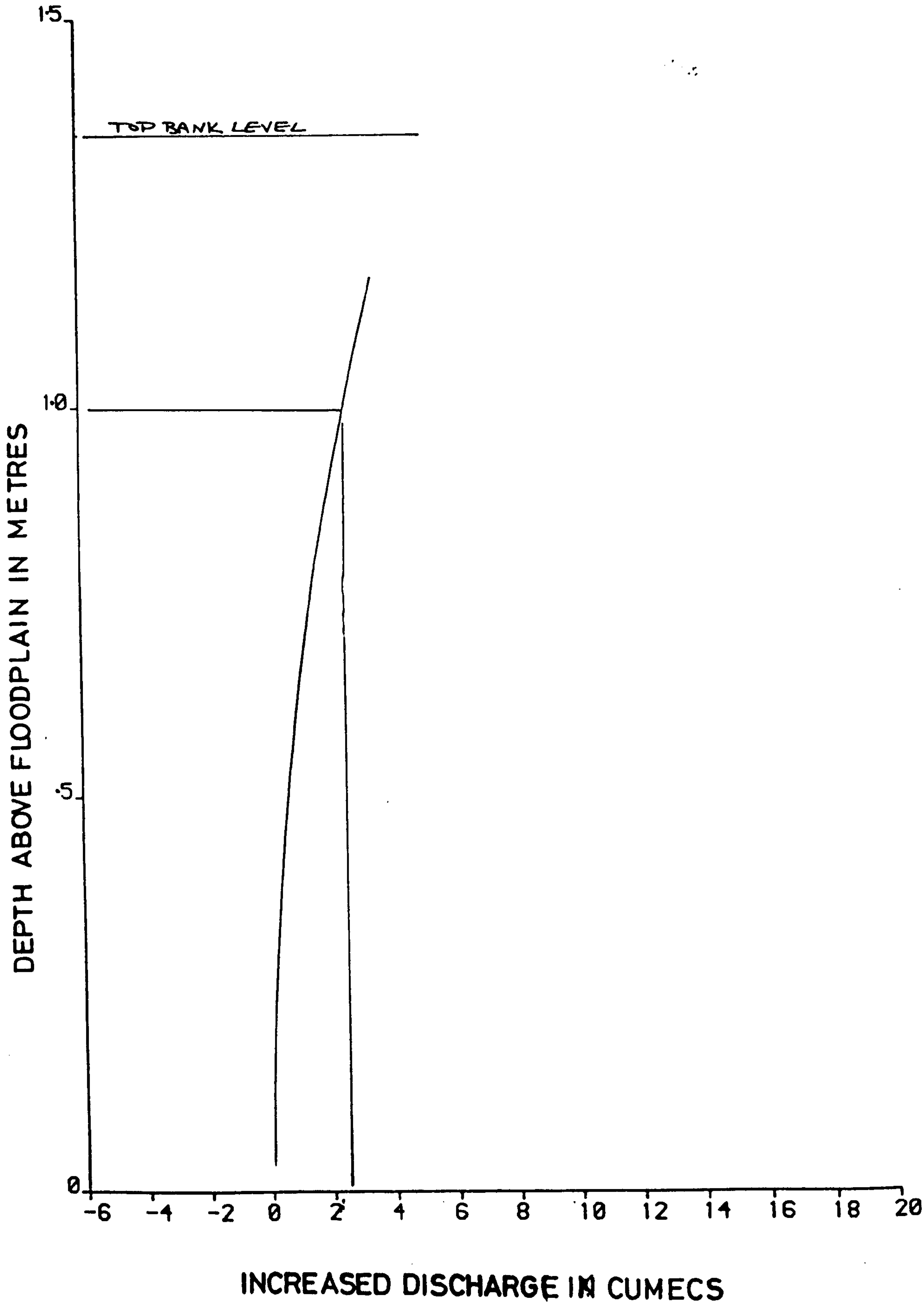


Figure 8.13
Plot of Discharge Difference Between S13 and S7
Using Fitted Curves

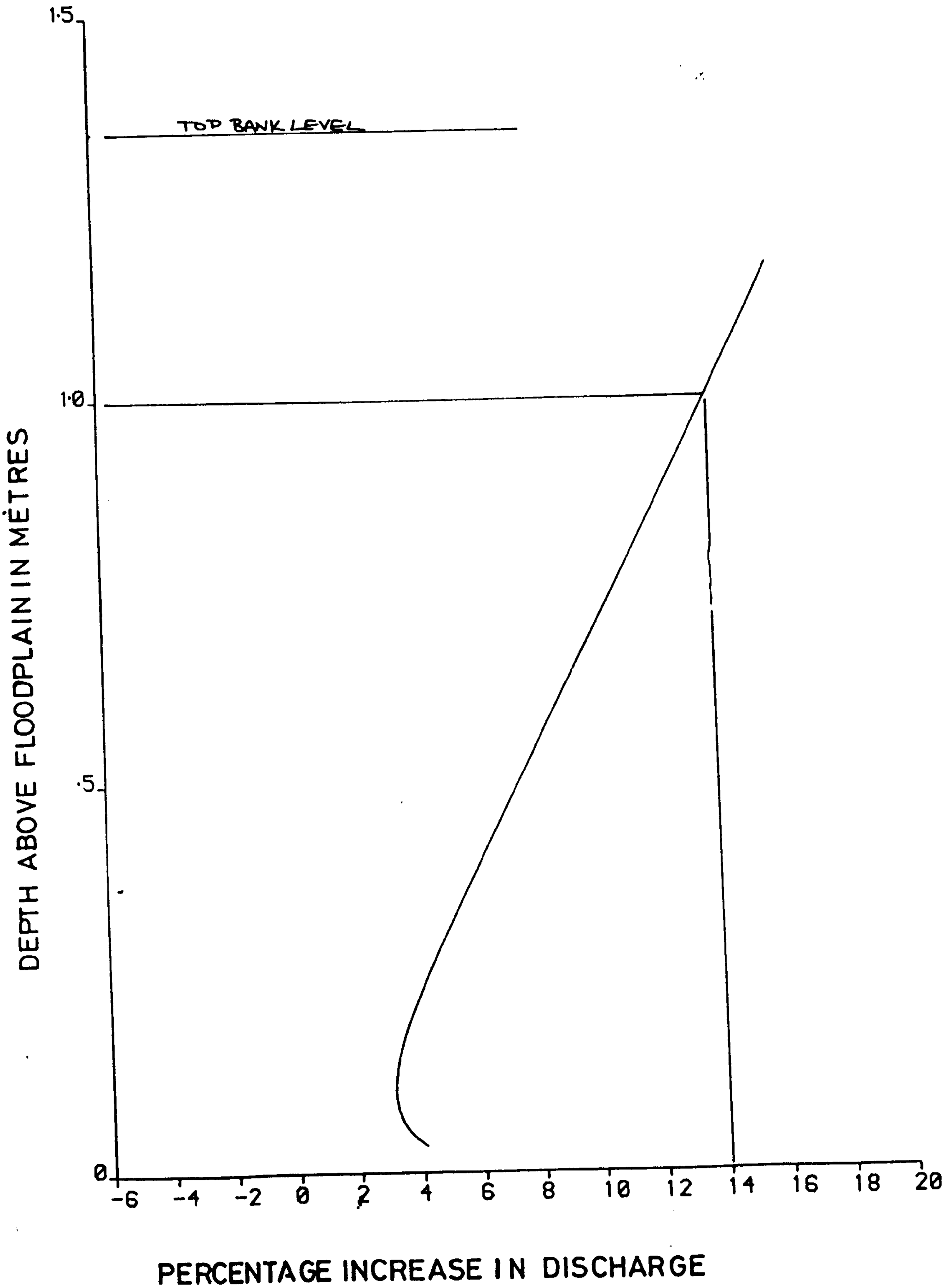


Figure 8.14
Plot of Percentage Discharge Difference Between S13 and S7 Using Fitted Curves

for the benefit of the natural wildlife, compared with complete clearance, S9, was to decrease the total discharge by only 10%, or 3 cumecs, at a floodplain flow depth of 1 metre.

3. Reducing the severity of the floodplain bends (localised increase of floodplain widths between 25%-40% - increasing the floodplain area by less than 5%) where gross separation could be seen to occur in the particular reach modelled, produced a significant increase in discharge capacity. At a floodplain flow depth of 1 metre, an increase of approximately 15% was measured. This corresponded to 2.5 cumecs for a heavily roughened floodplain, S13-S7, or 4 cumecs for a lightly roughened floodplain, S12-S11 .

4. The effect of clearing the main channel has not been fully established, because the main channel roughness in the prototype when cleared is not known, although it appears, S14-S13, that it might only provide a minimal increase in discharge capacity of around 5% .

8.2 Roughness Coefficients

An analysis of the roughness coefficients on the model and in the field, involved calculating the following parameters:

'n'	from	$n = \frac{R^{2/3} S^{1/2}}{V}$
λ	from	$\lambda = 8gRS/V^2$
k	from	$1/\sqrt{\lambda} = -2.01 \log_{10}\left(\frac{k}{14.83R}\right)$, λ – from above

The field data have been presented in Tables 5.2, 5.3 and 5.4 .The model data have been presented in Appendix A.6 page A.6.27 for Series S7 and S8, calculated at section 4730. More generalised roughness values have been calculated from the velocity porofiles and presented in table 7.2 .

To provide a comparison between calculated field and model 'n' values, the following table has been constructed.

	model data		field data	
Discharge Curves → ↓	S7	S8	84/85	85/86
bankfull flow	.05	.05	.044	.044
approx. equivalent 1m above bank in prototype	.055	.04	.045	.031

From chapter 6 on modelling, it has been shown that the 'n' values for the model should be about 10% larger than the 'n' values for the prototype. From the above table, it appears to be the case for bankfull flow, but for above-bank flow of about 1 metre, the difference in 'n' is about 20% . The model and field 'n' values were calculated for different cross-sections and so some variation in calculated 'n' might be expected.

Figures 8.15 to 8.17 are plots of the roughness coefficients, calculated from the velocity profile data table 7.2, against Reynolds number values. S2 approximates to S7 (see chapter 5 on proving the model) and in figure 8.15 exhibits a range of Manning 'n' values between .028-.042 for 5 cross-sections of the model, over the entire flow range. In figure 8.16, plotted friction factors, λ ,show a trend of decreasing values with increasing Re. This is at odds with the expected condition of decreasing relative roughness, k ,with increased flow depth and hence Re which ought to result in an increased λ from the Colebrook-White equation.
However, the effective roughness height, k, increases with increasing Re, from .02 - .10 metres, figure 8.17 .

From the field data for recorder 2, table 5.3, the roughness height, k, also increases with depth to a value of 0.6m and 0.2m for the 84/85 and 85/86 wet seasons at a flow depth of about 1 metre

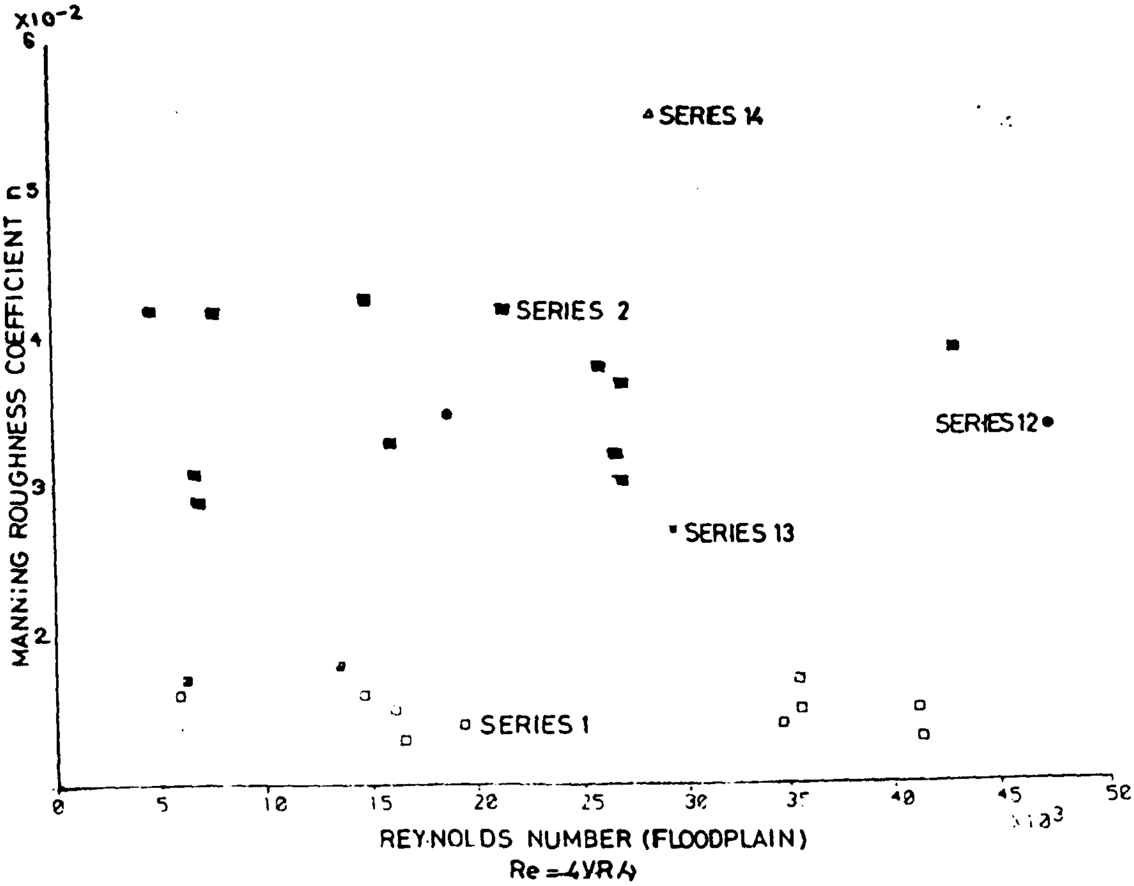


Figure 8.15
Plot of Manning Roughness Coefficient, n, vs Reynolds Number for Velocity Profile Data from Model

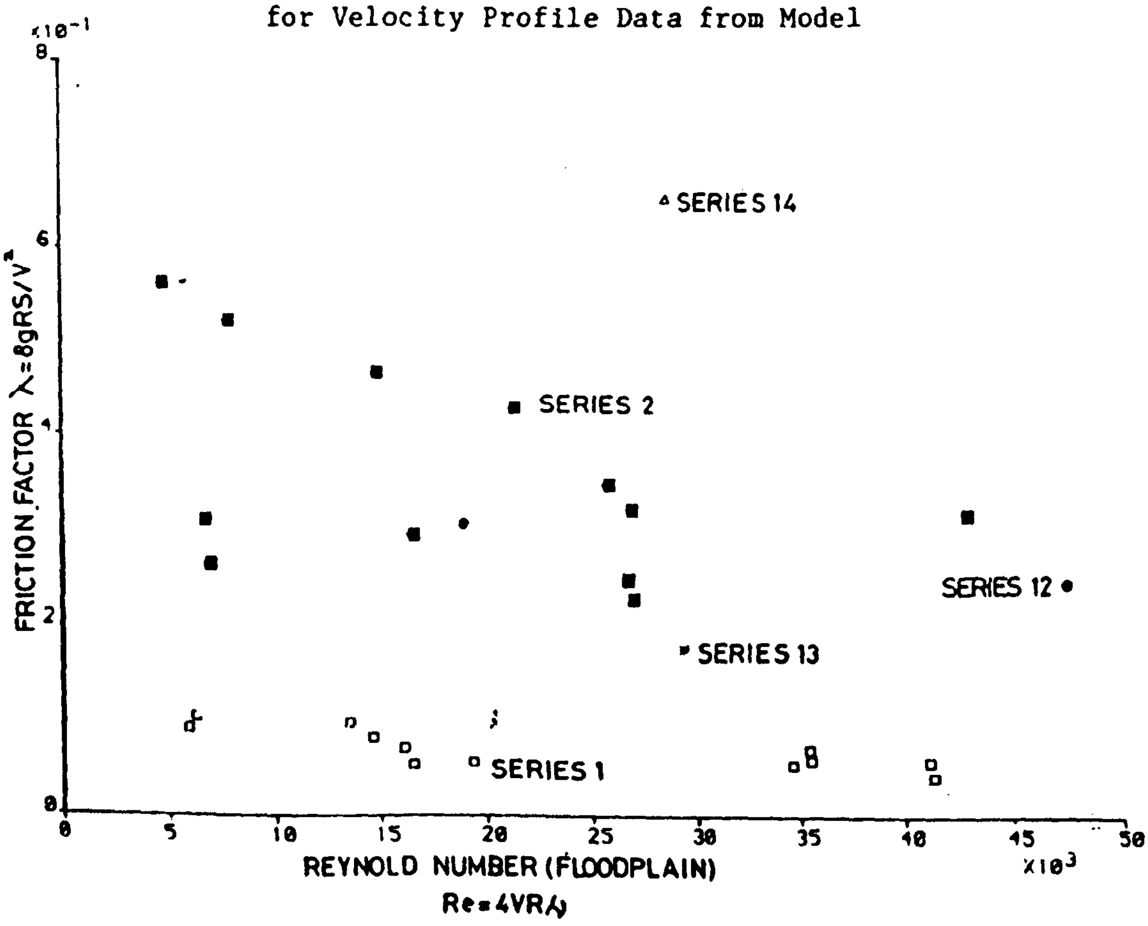


Figure 8.16
Plot of Friction Factor, λ, vs Reynolds Number for Velocity Profile Data from Model

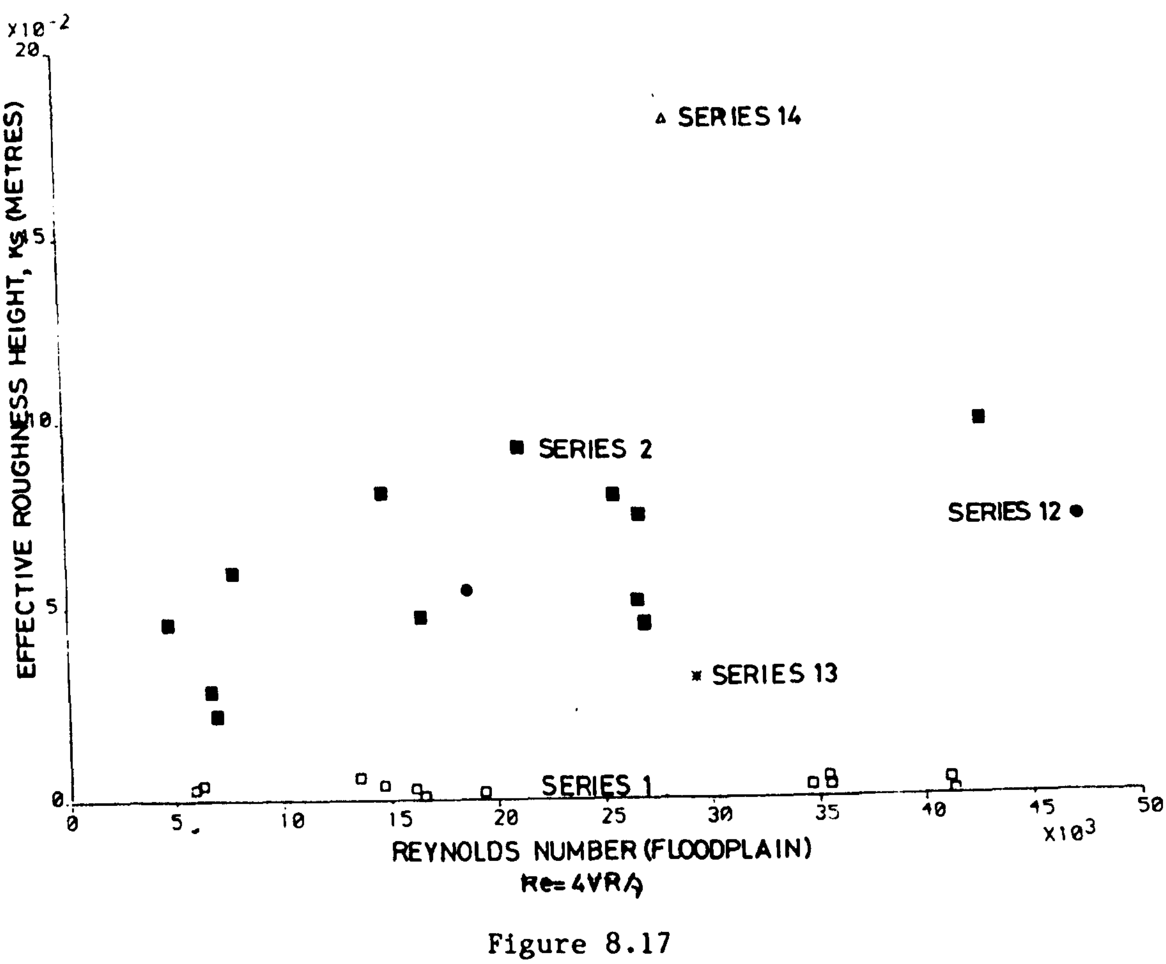


Figure 8.17
Plot of Roughness Height, k_s, vs Reynolds Number
for Velocity Profile Data from Model

above the floodplain.

In utilising effective roughness heights or Manning 'n' values for calculating the roughness of a river reach, it is clear that care must be taken. It seems that neither the roughness height, k, or 'n' can be considered constant for large relative roughnesses which prevail in densely vegetated floodplains.

Knight (59), in a paper on resistance coefficients in a tidal channel, found that roughness height, k, and Manning 'n' were not constant with varying depth .

8.3 Interaction Between Main Channel and Floodplain

8.3.1 Discharges in Main Channel and Floodplain

Comparisons have been made between bankfull discharge without floodplain flow and discharge in the main channel for various depths of overbank flow.

The ratio of main channel discharge/bankfull discharge for increasing floodplain hydraulic radius has been presented in figure 8.18. It is interesting to note that for all the series covered, the discharge in the main channel increased with overbank flow at section 4730 and decreased for all other sections.

The main channel discharge for section 4730 increased by up to 80% in the case of series 2, whereas the other sections experienced a decrease in discharges to as little as 20% of the original bankfull value. This might be explained as follows.

Firstly, consider the main channel and floodplain to be split at the horizontal interface between the two. Secondly, the highest recorded velocities in the model were always on the floodplain. See figures 7.6 to 7.20. At section 4730, the main channel is approximately parallel to the flood plain. As the overbank flow increases, the main channel flow will experience an apparent shear force across the horizontal interface assisting the flow within the channel and hence increasing the main channel discharge. Furthermore, as can be seen in figure 8.18, the rate of increase of main channel discharge at a low depth of flow is high as the largest differential velocities occur in this region. Figure 7.9, isovel plots at section 4730 for

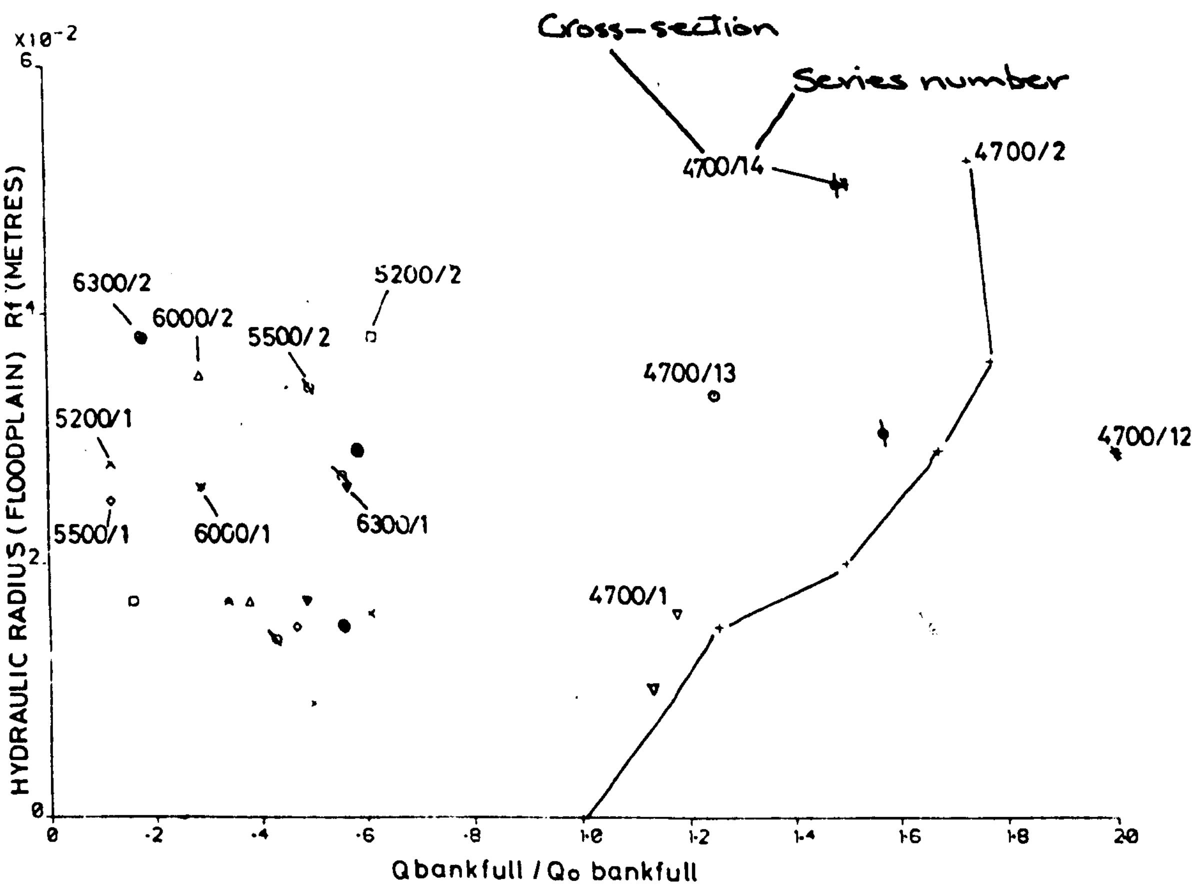


Figure 8.18
Plot of Main Channel Discharge/Bankfull Discharge vs Hydraulic Radius for Velocity Profile Data from Model

bankfull and just above bankfull discharges in Series 2, demonstrate the significant increase in main channel velocities that occur there as the river floods its banks. At higher depths, the velocities have readjusted and the rate of increase of discharge ratio reduces. The reduction in main channel discharge at sections 5200 to 6350 could be explained in a similar manner. The assisting shear force from the floodplain on the main channel in section 4730, becomes a transverse shear between 4730 and 5200, causing the main channel flow to 'spill' out onto the floodplain, leaving a much reduced discharge at 5200 and 5530 . The main channel from there does not recover and the discharge remains below the bankfull value beyond 6350. Figure 8.19 shows a plan of the model with location of the cross-sections marked in.

A practical consideration arising out of these results is what advantage there might be in actually dredging the main channel when at significant meanders, the main channel carries even less flow than when running bank full.

8.3.2 Flow Separation at Bends

As mentioned earlier, flow separation had been observed during the flow visualisation experiments. Marked separation can be seen in figure 8.20 for Series 1 at a discharge of 1.96 l/s. At a similar level of submergence, Series 7, at a discharge of 2.36 l/s, figures 8.21 and 8.22, show a markedly lower degree of separation, although some is evident from figure 8.22 .

Figure 8.23 shows Series 10 at a discharge of 6.33 l/s, the separation is quite distinct.

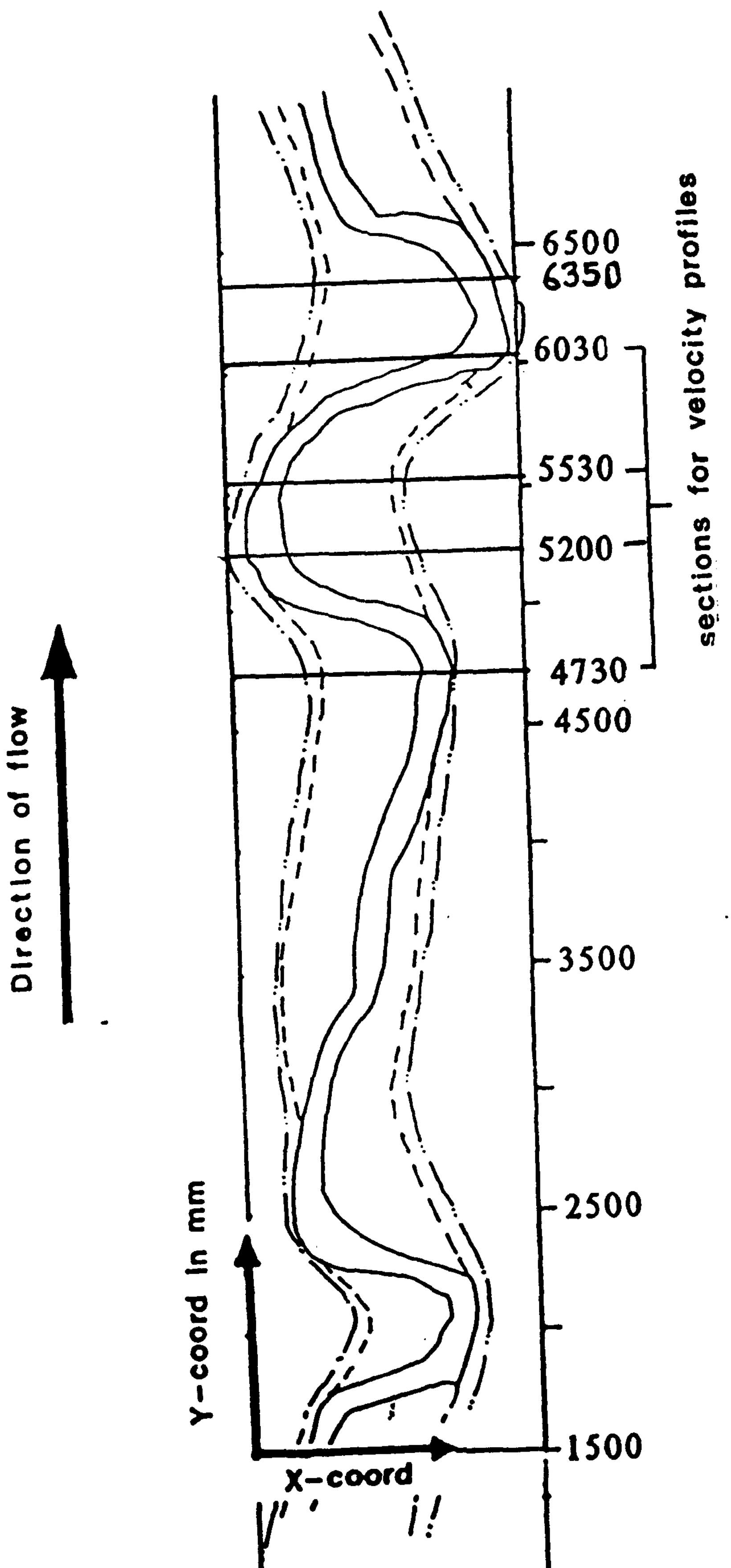


Figure 8.19
Plan of Model Showing Position of Velocity Traverses

Maximum separation of flow at the studied bend occurred in Series 1, where the highest velocities of flow were encountered. The mean velocity of floodplain flow in figure 8.20, was about 0.20 m/s. Reduced separation at a similar depth of flow, figure 8.22, occurred with a mean floodplain velocity of about 0.15 m/s . It seems likely, therefore, that separation at a bend is due partly to the incident flow velocity. Thus, it is reasonable to assume that if separation were observed in the model, it would be likely to occur in the prototype for the same conditions and at the same bend because the mean flow velocities would be 4 times greater (chapter 6 on modelling).

8.3.3 Evidence of Interaction Effect

Two photographs have been included to demonstrate the interaction effect, figures 8.24 and 8.25 . They show Series 1, at a discharge of 1.96 l/s between sections Y=4500 and 6000 . Figure 8.24 is a 'streak' photograph of a large quantity of small paper particles carried along on the moving water surface. The surface flow, evenly distributed at the left of the picture, is swept to one side by the strong crossflow in the main channel as it passes over it.
Marked on the picture is a 'line of interaction' where the surface flow is significantly affected by the lower flow.
Figure 8.25, shows individual particles affected by the flow. One path line has been marked on the photograph where the effect is very noticeable.

These pictures serve to show that an interaction exists between the main channel and floodplain flows but it is beyond the scope of this dissertation to quantify the effect.

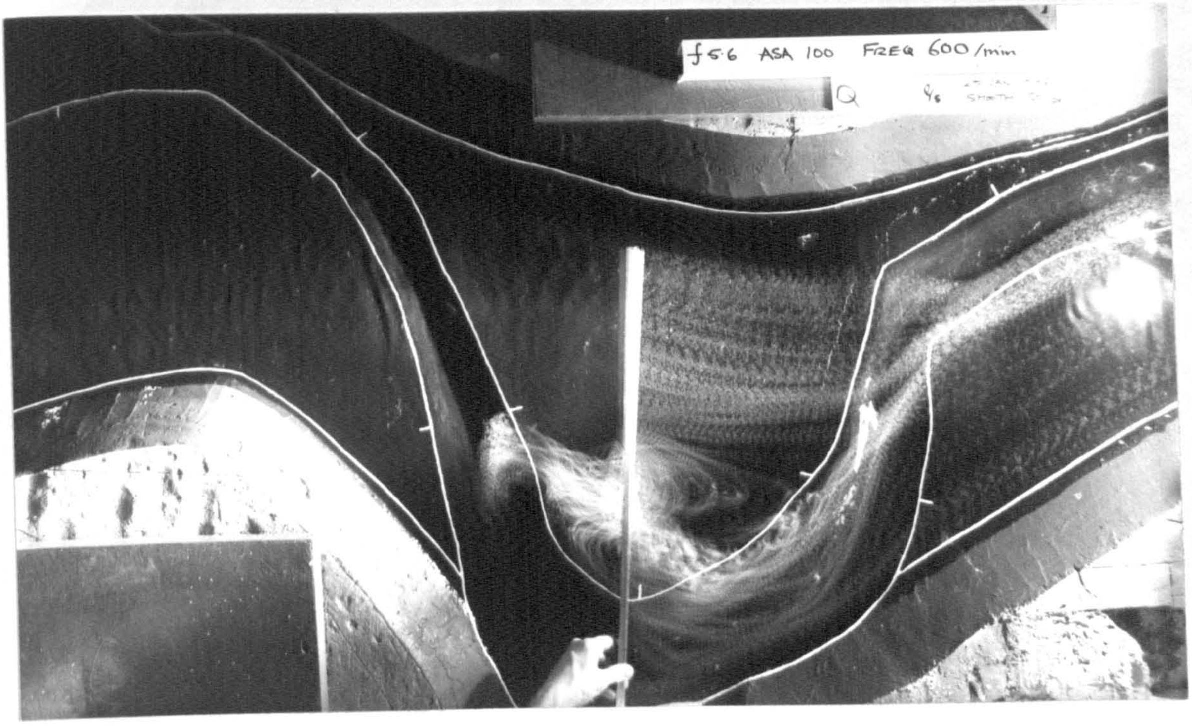


Figure 8.20
Surface Flow Betwen Y=5500 and Y=6500
Series 1,1.96 l/s

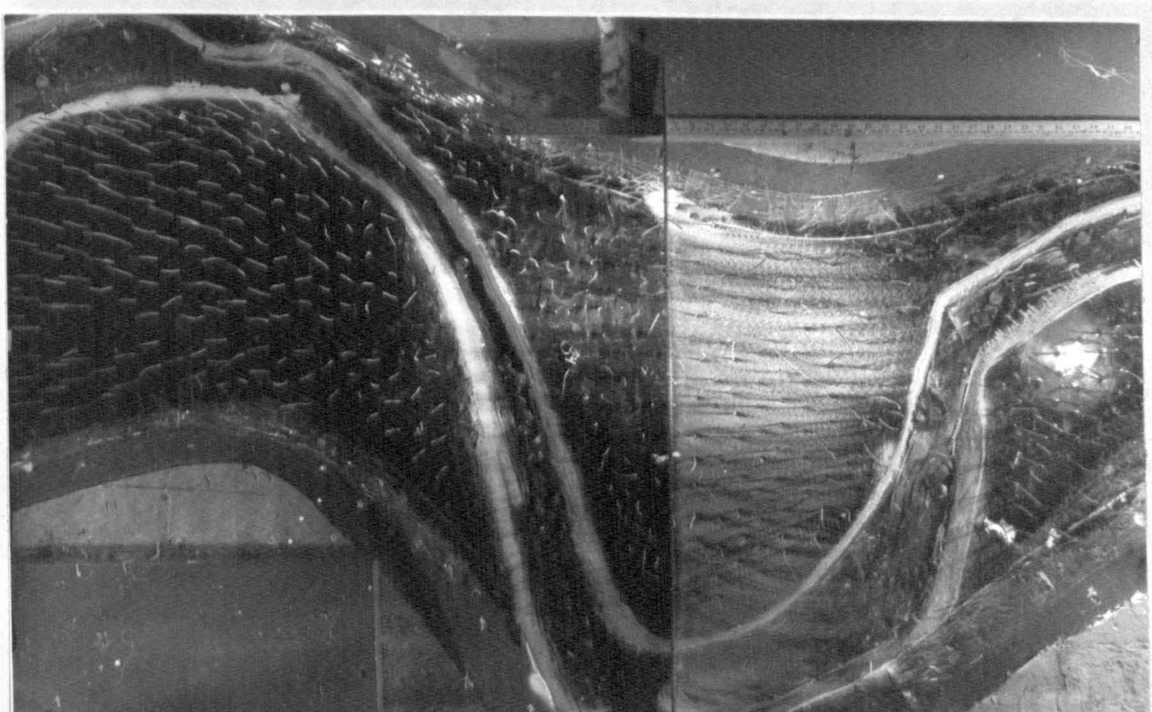


Figure 8.21
Surface Flow Between Y=5500 and Y=6500
Series 7, 2.36 l/s

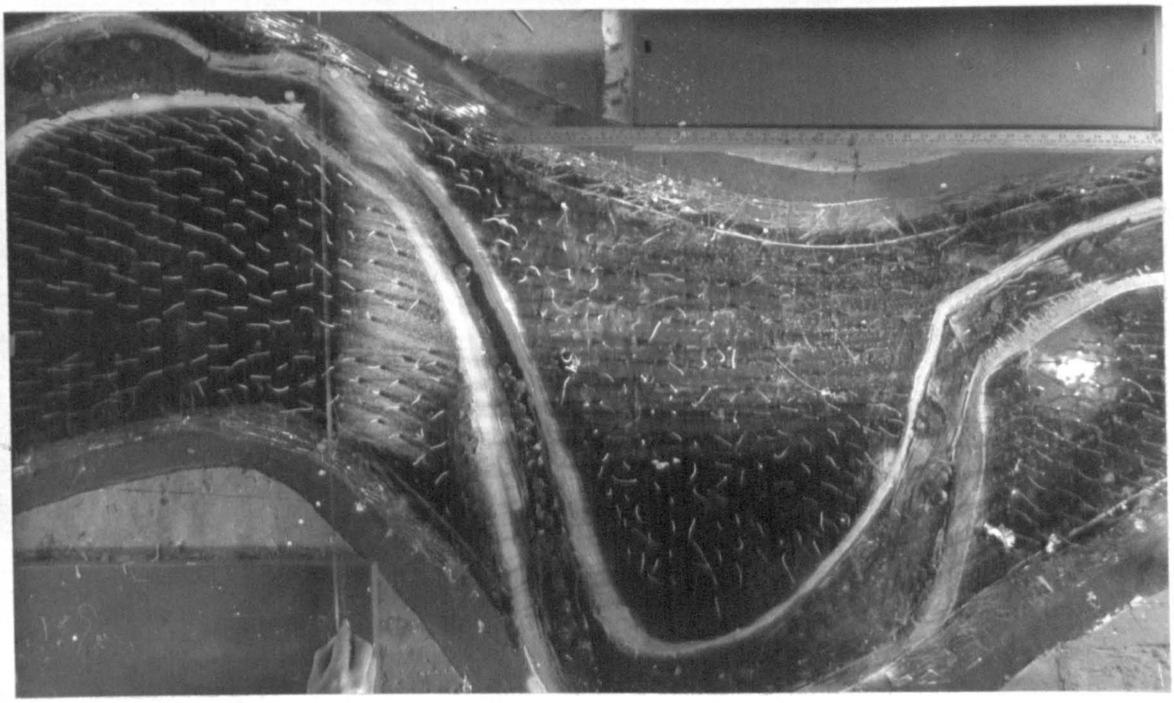


Figure 8.22
Surface Flow Between Y=5500 and Y=6500
Series 7, 2.36 l/s

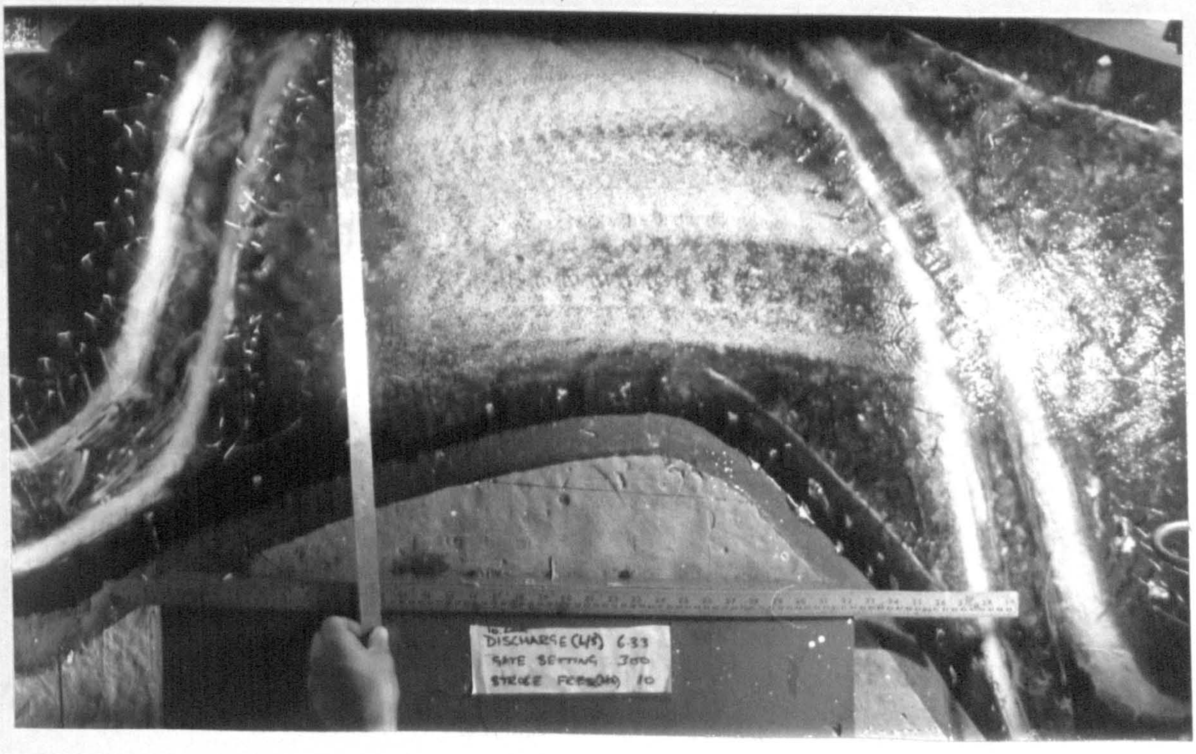


Figure 8.23
Surface Flow Between Y=5000 and Y=6000
Series 10, 6.33 l/s

Figure 8.24
Surface Flow Between Y=4500 and Y=5500
Series 1, 1.96 l/s

Figure 8.25
Surface Flow Between Y=4500 and Y=5500
Series 1, 2.36 l/s

8.4 Discharge Evaluation in Meandering Compound Channels - A Proposal

The calculation of discharge for flow in open channels of simple cross-section is well documented. Much research has been carried out on channels consisting of compound cross-section in which straight channels flow within straight parallel floodplains and many proposals for the calculation of discharge have been put forward. Due to the complexity of the problem, little has yet been proposed for discharge calculation in meandering compound channels. In this section, the author has proposed a method by which the discharge in the latter case with vegetatively roughened floodplains could be better estimated than is possible at present.

8.4.1 Evaluation of Roughness Coefficient on Vegetated Floodplain

To calculate the discharge in a river using one of the available methods, a knowledge of the roughness coefficients is required. It is possible to estimate these values using photographs of rivers matched to evaluated roughness coefficients as in Chow (5) or the author's data in chapter 5, figures 5.26 to 5.28 . This method is highly empirical and has no physical basis, therefore a great deal of experience is required to use it correctly. For vegetation roughness, the problem is even more complicated as the roughness characteristics of the vegetation, being flexible, will change with different flows and seasons.

Much work has been carried out on the resistance to flow in vegetated channels. The earliest work was produced by the U.S. Department of Agriculture, Soil Conservation Service. This has been reported by Cox and Palmer (57) and Ree and Palmer(64) who plotted Manning 'n' vs VR (product of hydraulic radius and mean section velocity) for various types of grasses, in channels with bed slopes ranging from 1% to 20%. From these they produced a set of retardance curves, with classifications from A (very high vegetal retardance) to E(very low vegetal retardance). With these were included a description of all the vegetation tested and labelled with a retardance class (A to E). Subsequent research by Eastgate, (58) showed that this data could not be extended to channels with bed slopes of less than 1% as the data, from subsequent research, had proved to be slope dependent. As most natural vegetated open channels had bed slopes smaller than 1%, this posed a problem in using the USDA data. Kouwen et al (60,61,62,63) investigated flow over plastic flexible roughness in an attempt to produce a physically based resistance function. They found that velocity profiles over vegetation in their laboratory investigations were logarithmic and that a logarithmic expression relating the Darcy-Weisbach friction factor, λ , to the relative roughness applied.

A method of calculating friction factors for vegetal roughness is presented in "Watershed and Stream Mechanics" from the U.S. Department of Agriculture, Soil Conservation Service (67). In it, the data produced by Kouwen et al, have been used together with data from the "Handbook of Channel Design for Soil and Water Conservation", USDA, 1954 (68), presented here in table 8.1 . A work sheet has been included, table 8.2, which begins with identifying the type of grass and producing a stiffness value for it from a similar grass listed in table 8.1 .The remaining calculations are based on the equations from Kouwen to calculate the deflected grass height, k, critical shear stress, U*crit, from which, having

Retardance Class (1)	Average Height h in millimeters (2)	Stiffness MEI in Newtons-meters squared (3)	Cover Type (4)	Cover Condition (5)	Calibrated Stiffness MEI in Newtons-meters squared (6)
A	910	300	Weeping lovegrass	Excellent stand, tall, (average 760 mm)	200
			Yellow bluestem Ischaemum	Do tall, (average 900 mm)	-
			Rhodes Grass (Australian).	Excellent stand (average 690 mm)	140
A/B			Kikuyu Grass	Excellent stand Iaverage 420 mm)	47
B	610	20	Kudzu	Very dense growth, uncut	-
			Bermudagrass	Good stand, tall, (average 300 mm)	17
			Native grass mixture (little bluestem, blue grama, and other long and short midwest grasses . .	Good stand, unmowed	20
			Weeping lovegrass	Good stand, tall, (average 600 mm)	30
			Lespedeza sericea	Good stand, not woody, tall (average 500 mm)	10
			Alfalfa	Good stand, uncut, (average 275 mm)	4
			Weeping lovegrass	Good stand, mowed, (average 330 mm)	6
			Kudzu	Dense growth, uncut	-
			Blue grama	Good stand, uncut, (average 330 mm)	6
			Bluegrass (Australian) . .	(average 340 mm)	18
			Dallas	Uncut (average 760 mm)	20
B/C			African Star (Australian)	(average 290 mm)	4
C	200	.5	Crabgrass	Fair stand, uncut (250-1200 mm)	
			Bermudagrass	Good stand, mowed (average 150 mm)	
			Common lespedeza	Good stand, uncut (average 280 mm)	3
			Grass-legume mixture--Summer (orchard grass, redtop, Italian ryegrass, and common lespedeza)	Good stand, uncut (100 to 125 mm)	
			Centipedegrass	Very dense cover (average 150 mm)	2
			Kentucky bluegrass	Good stand, headed (150 to 300 mm)	
D	100	.05	Bermudagrass	Good stand, cut to 64 mm	.15
			Common lespedeza	Excellent stand, uncut (average 114 mm)	.10
			Buffalograss	Good stand, uncut (75 to 150 mm)	.16
			Grass-legume mixture--fall, spring (Orchardgrass, redtop, Italian ryegrass, and common lespedeza	Good stand, uncut (100 to 125 mm)	.07
			Lespedeza sericea	After cutting to 50 mm Very good stand	.015
			Kikuyu (Australian) . . .	After cutting to 107 mm	.17
			Kentucky Bluegrass	Cut to 75 mm	.10
E	40	.005	Bermudagrass	Good stand, cut to 38 mm height	
			Bermudagrass	Burned stubble	

Note: Covers classified have been tested in experimental channels.
Covers were green and generally uniform.

Table 8.1
Vegetal Retardance and Stiffness Values for Different Grasses
(U.S.D.A Soil Conservation Service)

Work Sheet: Grassed Channels

INPUTS:

height of grass:	ft x .3048 in x .0254	$h =$	m
stiffness:	(from Table 2)	$MEI =$	$N - m^2$
channel slope:	ft/ft, m/m	$S_o =$	m/m
depth:	ft x .3048	$d =$	m

OUTPUTS:

average boundary shear		$\tau = \rho g d S_o =$	Pa
shear velocity		$U_* = \sqrt{g d S_o} =$	m/s
critical shear stress			
U_{*crit} = minimum of	$0.0.28 + 6.33\ [MEI]^2$	=	m/s
	$0.23\ [MEI]^{0.106}$	=	m/s
	Minimum	=	m/s
classification	U_* / U_{*crit}	=	
deflected grass height	$k = 0.14h\ \{(\frac{MEI}{\tau_o})^{.25}/h\}^{1.59}$	=	m
if h less than k, set k = h		$k =$	m

U_*/U_{*crit}	
0 - 1	$\frac{1}{\sqrt{\lambda}} = 0.15 + 1.85\ \log_{10}(d/k)$
1 - 1.5	$\frac{1}{\sqrt{\lambda}} = 0.20 + 2.70\ \log_{10}(d/k)$
1.5 - 2.5	$\frac{1}{\sqrt{\lambda}} = 0.28 + 3.08\ \log_{10}(d/k)$
2.5 - ∞	$\frac{1}{\sqrt{\lambda}} = 0.29 + 3.50\ \log_{10}(d/k)$

=

velocity $\quad V = \frac{1}{\sqrt{\lambda}} \sqrt{8 g d S_o} = \frac{1}{\sqrt{\lambda}} (2.83)\ U_* =$ m/s

Table 8.2
Work Sheet for Calculating Friction Factors in Grassed Channels
('Watershed and Stream Mechanics', USDA Soil Conservation Service)

calculated the shear velocity, $U^* = \sqrt{gdS}$, values of a and b in the equation

$$1/\sqrt{\lambda} = a + b(\log 10(d/k)$$

can be determined

where y = depth of flow on the floodplain
and the 'n' value can be directly found from

$$n = \sqrt{\frac{8g}{\lambda}}\, d^{1/6}$$

If the type of grass cannot be identified from table 8.1, the descriptions given could be applied to identify similar grasses.

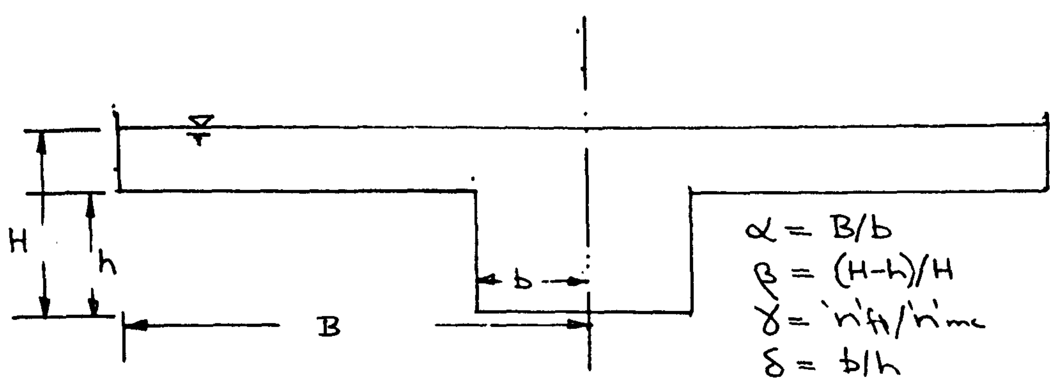
8.4.2 Model Data for Meandering Compound Channel Within Straight Floodplains

The Corps of Engineers (US Army) at the Waterways Experiment Station, Vicksburg, Mississippi in March 1956, produced a Technical Memorandum entitled "The Hydraulic Capacity of Meandering Channels", (40). In it they investigated the various factors which might affect floodway capacity. The specific objectives were to determine the effects on floodway capacity of:

1. radius of curvature of bends
2. sinuosity of channel
3. depth of overbank flow
4. ratio of overbank area to channel area and

5. overbank roughness.

The tests of interest in this analysis were carried out on a floodplain 16ft wide and trapezoidal main channel with top width of 2.5ft and bottom width of 2 ft. Depths of floodplain flow were up to 0.3 ft and the depth of main channel was 0.5 ft. These dimensions produced a floodplain/channel width ratio, α, of 8, a depth ratio, β, between 0.17 - 0.38 and an aspect ratio, δ, of 4.5 . A sinuosity, s, defined as the main channel length/floodplain length, varied between 1.0 and 1.57. The ratio of floodplain roughness/main channel roughness, γ, varied between 1 - 3. The floodplain bed slope was .001 . These dimensionless parameters, used previously in chapter 2, have been redefined below with the use of a simple diagram.



The author rearranged the 'Vicksburg' raw data and produced a plot of %change in total discharge in the model vs depth ratio for different roughness ratios and sinuosities. Figure 8.26 is a presentation of the rearranged data.

8.4.3 Calculations for Meandering Compound Channel

The previous two sections have outlined;

1. a method of calculating the roughness values for a vegetated floodplain, and

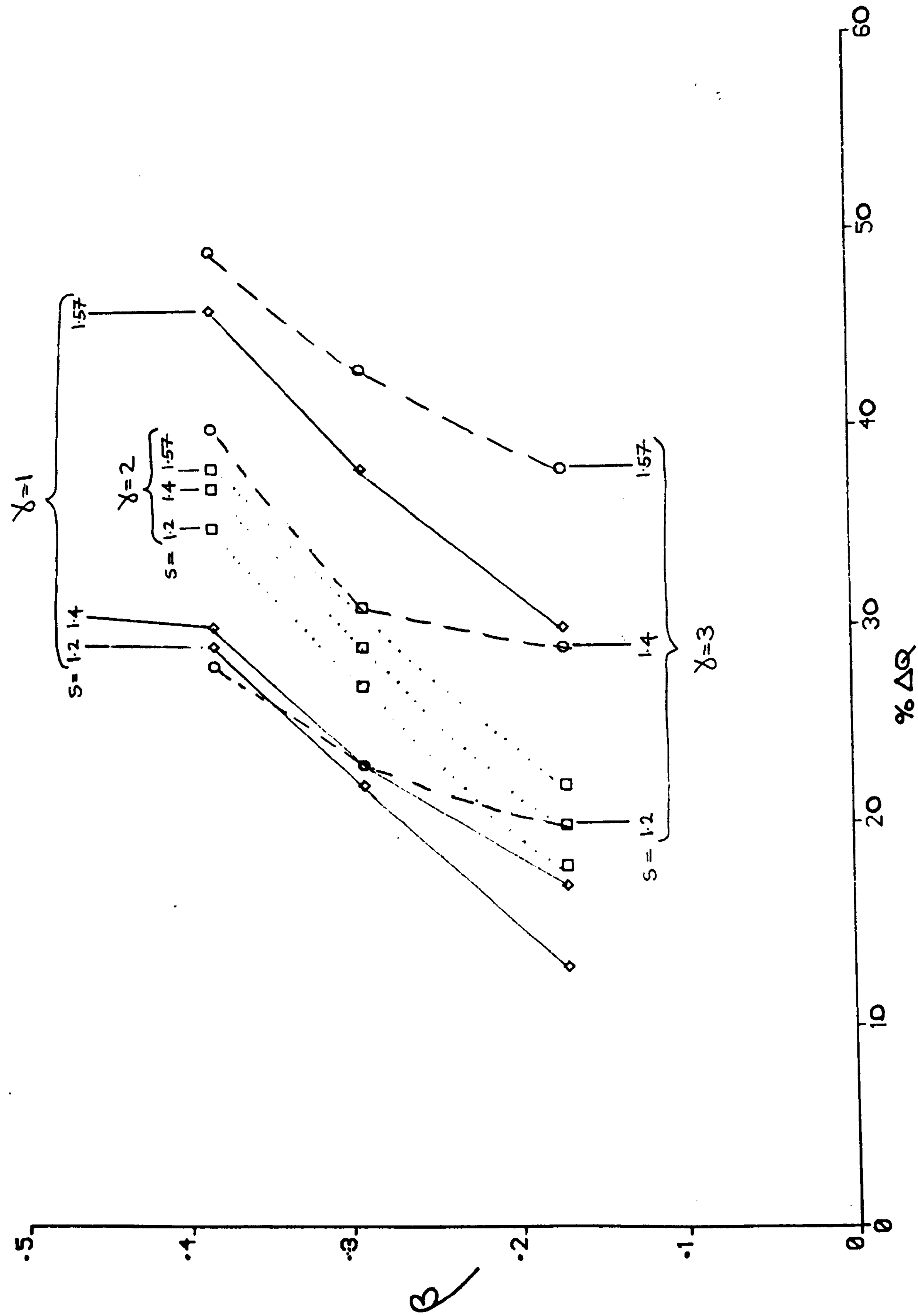


Figure 8.26
Percentage Discharge Decrease over Straight Compound Channel
vs Depth Parameter, β, for varying sinuosity, s, and Roughness Ratio, γ

2. a method of correcting the discharge calculated from an idealised prismatic compound channel, using the friction factors found, to the actual case of meandering compound channel.

It is important to stress, before illustrating the method with an example, that the calculation of the main channel bankfull friction factor has not been dealt with. This roughness value must be either found by inspection of known similar reaches or by stream gauging. The correction factors proposed in sub-section 8.4.2 are for very limited geometries only, the ranges of which have been given.

Taking the parameters from Wojcik (50), for designing the Roding Flood Alleviation Scheme (chapter 1),

n floodplain = 0.032
2B (width) floodplain = 30 metres
H-h (depth) floodplain = 1.35 metres

n main channel = 0.045
2b (width) main channel = 6 metres
H total depth = 2 metres

for a designed discharge of 50 cumecs.
These give:

width ratio, α, (B/b) = 5
maximum depth ratio, β, (H-h)/H = 0.325
aspect ratio, δ, b/h = 4.5
roughness ratio, γ, (nfp/nmc) = 0.7

sinuousity, approximately the ratio of bed slopes, s = 9/7 = 1.3
floodplain bed slope S_o = 1/900

Some of these parameters fall outside the bounds of the "Vicksburg" model;

width ratio α = 6.4
aspect ratio δ = 5
minimum roughness ratio γ = 1
floodplain bed slope, S_o, = 1/1000

It will be a useful exercise, however, to deomonstrate the practicality of introducing a correction factor for river meander, given sufficient laboratory data. Figure 8.27, is a reproduction of figure 8.26, with the calculations for discharge correction included. No correction could be made for the different width ratios, or floodplain bed slopes but an approximate correction has been made for the 'out of range' roughness ratio. The assumptions made, therefore, are that the small difference in width ratios and bed slopes between the "Vicksburg" model and River Roding Flood Alleviation Scheme, can be ignored. Without any further knowledge of the effect of a roughness ratio of less than unity, the conservative value of reduction in discharge for γ =1 has been used. From figure 8.27, this gives a reduction in discharge of 25%, for a floodplain depth of flow of 1 metre, ϱ =0.3.

Therefore, the calculated discharges for the design of the Flood Alleviation Scheme, based on the given design parameters, would have been overestimated by about 25%. Or, presented another way, the reach between chainages 0m to 1200m, designed to carry a flow of 50

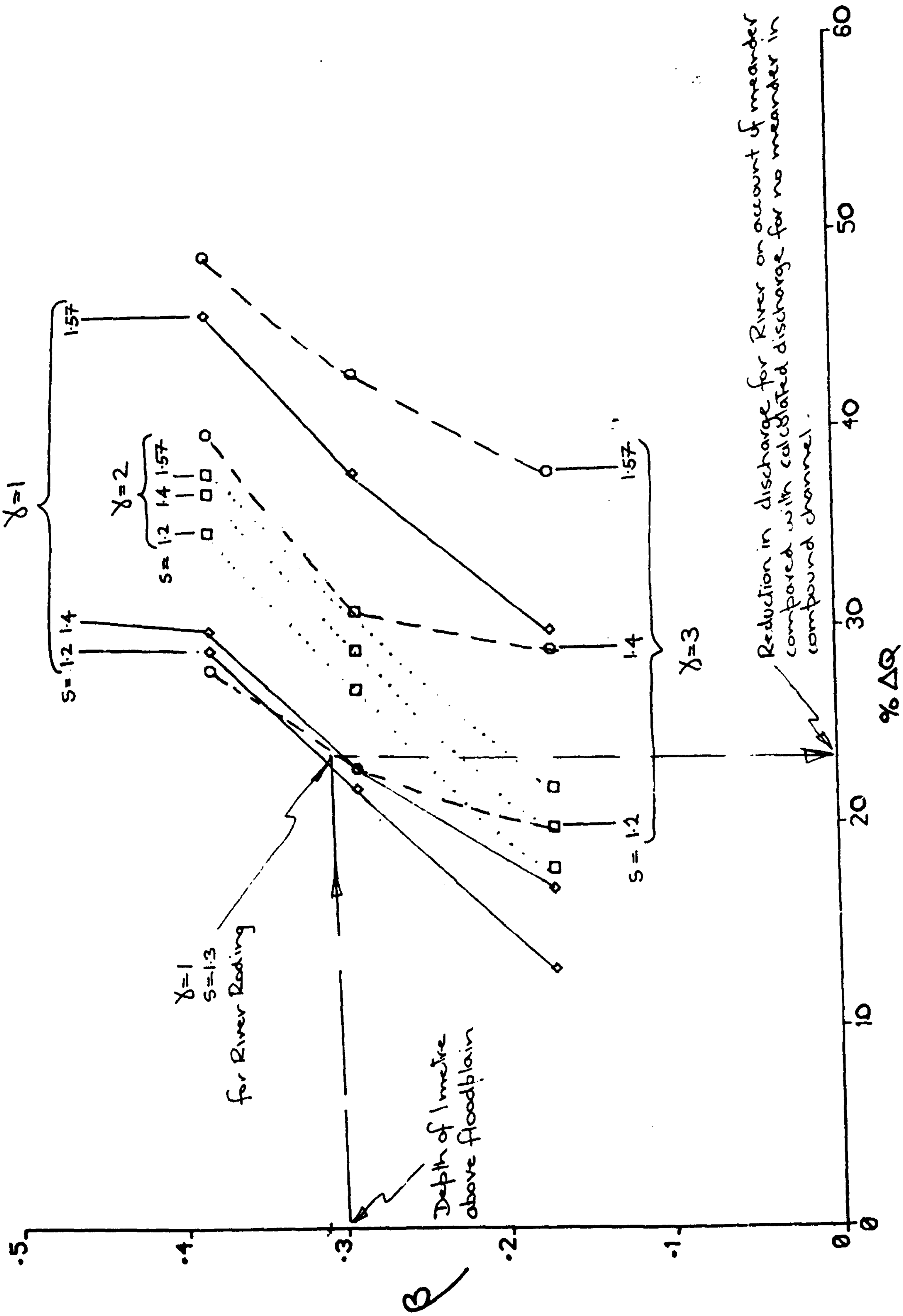


Figure 8.27
Reproduction of Figure 8.26 with Calculations for River Roding Marked on

cumecs at a flow depth of 1.35 metres on the floodplain, would reach this maximum designed flow depth, at a discharge of around 35 to 40 cumecs. Wojcik reported, that the River Roding experienced a major flood of 25 cumecs in December 1979. The estimated depths of flow between chainages 0 m to 1200 m were 18% greater than expected although the depths of flow recorded between chainages 1200 m and 3200 m were approximately the designed values.

Given the simple design parameters used by engineers in calculating expected discharges and levels for rivers, it is worth applying an empirical factor, similar to one described above, for the fairly common case of a meandering river within vegetatively roughened floodplains. Limited geometries have been considered in the analysis and it would be worthwhile extending the range of information for different roughness ratios between main channel and floodplain and depth of flow. Experimentation using model geometries based on natural river dimension ratios would be valuable.

CURVE	a	b	c
S7	.849	15.5	2.69
S8	1.17	9.45	15.67
S9	1.84	4.85	22.6
S10	0.75	13.81	11.6
S11	.736	14.11	10.84
S12	.737	9.96	18.90
S13	.904	15.45	5.31
S14	2.00	15.58	4.88

$y = a + bx + cx^2$

y – discharge

x – depth

Table 8.3
Polynomial Constants for Best Fit Curves S7 to S14

CHAPTER 9

Conclusions and Proposals for Future Research

Chapter one laid out the general aims for the research programme. In this final chapter, the author summarises the conclusions arrived at and to what degree the aims of the project have been achieved.

Briefly, the aims of the project had been to;

1. determine the effect of vegetated floodplains on the discharge capacity of the River Roding Flood Alleviation Scheme and

2. investigate the turbulent interaction mechanism betwen the main channel and its adjacent floodplains.

9.1 Conclusions

The conclusions can be best stated in note form.

The study of past research on compound channel flow in chapter two has shown the following.

1. Standard resistance formulae do not take into account the turbulent energy losses which occur across the fluid interface between main channel and floodplain.

2. The turbulent interaction between main channel and floodplain is extremely complex.

3. Very litle research has been carried out on 'real rivers' but

mainly on laboratory models with prismatic cross-sections.

The field study has shown;

1. that the presence of vegetation growth on the floodplains of the Roding Scheme has a significant effect on its discharge capacity. Chapter 5 shows the effect of varying the roughness of the floodplain over two successive wet seasons on the river. For no river maintenance on one hand and almost complete floodplain clearance on the other, at a flow depth of 1 metre on the floodplain, over 40% increase in discharge capacity was observed.

The model Study has shown the following.

1. Turbulent losses in the river could only be reproduced in the model with use of non-submerged rigid roughness elements as large scale turbulent eddies, observed in the river, did not reach to the surface in the model when using small scale roughness elements.

2. Leaving a 2 metre margin of reeds adjacent to the floodplain in line with wildlife conservation policy only reduces the capacity of the reach compared with a policy of complete clearance, by about 10%.

3. Flow separation at severe floodplain bends results in 'dead water' zones on the floodplain and leaving these areas uncut has minimal effect on flow capacity.

4. Reducing the severity of selected floodplain bends could significantly increase dicharge capacity. In the modelled reach, an

increase of 15% was obtained in this manner for an overbank flow depth of 1 metre and increased floodplain plan area of less than 5%.

5. The main channel in a meandering river, such as the Roding, might contribute less to the total flow at increasing overbank depths due to the shear interaction at the interface between the main channel and floodplain. This has been demonstrated in the model in chapter 8. This indicates the possible lack of importance of clearing the main channel in an attempt to increase the capacity of the reach.

9.1.1 General

6. Roughness coefficients for the model and prototype were not constant with increasing depth of flow for a particuar surface roughness. It is important, therefore, to use any evaluated roughness coefficients, λ, effective roughness heights, k, or friction factors with care in calculating river discharge capacities. For example, the Manning roughness values calculated in chapter 5 and linked with photographs of floodplain vegetation can only be use for the stated depths of flow on the floodplain.

7. A proposal was made, chapter 8, for including a correction for the meander in discharge calculations for a compound reach. In brief, this entailed first of all calculating the discharge in the compound reach assuming a straight main channel bounded by a straight floodplain by the normal method. Then a correction factor, percentage reduction in discharge, could be cal culated from a graph relating the discharge reduction to depth of flow, sinuosity, roughness ratio between floodplain and main channel for particular river geometries. A very limited range of geometries was available

9.2 Proposals for Future Research

In the light of so little field data being available on compound rivers, it would be valuable to extend the data measurement programme on the River Roding Alleviation Scheme. Velocity traverses could be taken to measure the distribution of flow in the main channel and on the floodplain to confirm the contribution of the main channel to the total flow.

Much research has been carried out in the past aimed at gaining a better understanding of the interaction phenomenon particularly in straight channels between the main channel and the floodplain. In this thesis, the author has pursued the argument that whilst research in this area is very valuable and of long term significance, there is a real need for the development of empirical solutions to the problems of designing compound reaches containing a meandering main channel.

It was proposed in chapter eight that model data incorporating all the variable features which affect the total discharge in a meandering compound channel might be used to determine a correction factor to take the main channel meander into account. The use of the "Vicksburg" model data was an attempt to demonstrate this point.

Simple empirical design formulae are still very useful and relevant. The River Roding Flood Alleviation Scheme was designed in such a manner and has been used in this thesis as an example of applying a correction factor to the design discharges obtained to take into account the river meander.

It is felt, therefore, that much useful knowledge might be gained in pursuing an empirical approach to the compound channel problem by extending investigations on the same lines as the "Vicksburg" experiments. Channel sinuosity, main channel-floodplain roughness ratio and relative width could be three parameters that might be varied in gaining a better working knowledge to cope with the problem.

9.3 Prospects for Numerical Modelling in Compound Channel Flows

Although not pursued in this dissertation, the author appreciates that a numerical modelling of compound flows in rivers is highly desirable. The calculations required can now be carried out on very powerful computer systems. Many numerical models utilise empirical equations for flow. It might be feasible therefore to use any empirical correction factors found as a result of the proposals suggested in 9.2 for meandering main channels within floodplains into these numerical models.

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APPENDIX TO:

A LABORATORY AND FIELD INVESTIGATION INTO THE DISCHARGE CHARACTERISTICS OF AN EXPERIMENTAL FLOOD ALLEVIATION SCHEME ON THE RIVER RODING IN ESSEX

D.J Searle

Thesis Submitted for the degree of Ph.D
in the University of Bristol

APPENDIX

Appendix references are referred to by chapter number from the thesis. Appendices were required for chapters 4,5,6 and 7 only.

CONTENTS

APPENDIX A.4

PROGRAMME LISTING FOR - LONGBAS

```
 10REM******************************
 20REMPROG LONGBAS OCTOBER 1985 WRITTEN BY D.J. SEARLE
 30REM RUNS IN CONJUNCTION WITH LONGMC
 40REM PAGE IS SET AT &1C00
 50REM HIMEM IS SET AT &4000 LEAVING DATA STORE FROM &4000 TO &5800
 60 @%=131594
 70MODE7
 80 PORTB = &FE60                    )
 90 DDRB = &FE62                     )
100 ADPTR=&70                        )
110 OSFIND=&FFCE                     )
120 OSBYTE=&FFF4                     )
130 PT=&4000                         )
140 HIMEM=PT                         )  naming address locations
150 DTASTR=PT+50                     )
160 delay=PT                         )
170 steps=PT+9                       )
180 filename=PT+10                   )
190 fchan=PT+20                      )
200 eflag=PT+21                      )
210 dist=PT+22                       )
220REM***************************
230 AA$=""                           )
240 AB$=""                           )
250 AC$=""                           )
260 AD$=""                           )    inititialise BASIC parameters
270 S=0                              )
280 DISC=5                           )
290 A0%=100                          )
300 DIM Y%(12)                       )
310 CLOSE£0
320REM**************************
330 *LOAD LONGMC 1A00                     load assembled LONGMC
340 start=&1A00                      )
350 pulse11=&1A37                    )
360 pulse22=&1A61                    )
370 on1=&1A13                        )
380 on2=&1A25                        )
390 off1=&1A1C                       )   define LONGMC address
400 off2=&1A2E                       )   locations
410 blnkfile=&1B1E                   )
420 openfile=&1B2B                   )
430 closefile=&1B38                  )
440 REM******************************
450 PROCintro                        )
460 PROCoptions                      )
470 PROCprobeset                     )   start of programme
480 PROCset                          )   calling procedures
490 PROCparameter                    )
500 PROCrun                          )
510 IF AD$="S" THEN 470
520 REM**************************
530MODE4
540 IF PLT$="R" THEN RESTORE 590                   ) read in
550 IF PLT$="A" THEN RESTORE 600                   ) appropriate
560 FOR X=1 TO 11                                  ) correction
```

```
570 READ Y%(X)                                              ) factors for
580 NEXT X                                                  ) averaged data
590 DATA 0,1,0,2,8,10,9,5,0,-1,-1                           )
600 DATA 0,17,36,52,64,80,99,121,144,163,182                )
610REM*****************************:
620REM DTASTR=base address of storage locations
630REM readings=readings taken during run
640REM R=readings to average
650REM RD=stepper pulses between unaveraged readings.
660REM Z%=averaged and corrected reading
661REM DIST=distance between averaged readings
```

UNIT 6

```
670 L=0
680 tot=0
690 N1=DTASTR
700 hiaddr=?ADPTR+256*(ADPTR?1)
710 readings=INT((hiaddr-DTASTR)/2)
720 C%=POS0%/500-2
730 R=INT(100*readings/(6500-POS0%))
740 FOR MM=0 TO 2*(R-1) STEP 2          )
750 tot=tot+(N1?MM+256*(N1?(MM+1)))/64  )  calculate first
760 NEXT MM                             )  averaged value
770 Z1%=INT(tot*10/(A0%*R))             )  Z1%
780 DIST=RD*R/25.34
790 C=DIST/2+(POS0%-1500)
800 FOR N=N1 TO hiaddr-2*R STEP 2*R
810 IF C<500 THEN GOTO0870
820 IF C%=11 THEN GOTO0990
830 REPEAT
840 C=C-500
850 C%=C%+1
860 UNTIL C<500
870 tot=0
880 FOR M=0 TO 2*(R-1) STEP 2           )
890 tot=tot+(N?M+256*(N?(M+1)))/64      ) calculate averaged values Z%
900 NEXT M                              )
910 Z%=INT(tot*10/(A0%*R))-Z1%          )
920 Z%=Z%+INT(DEPTH0*10+((Y%(C%+1)-Y%(C%))*C/500+Y%(C%)))   ) correct Z%
930 C=C+DIST
940 DTASTR?L=Z% MOD 256                 ) store Z%
950 DTASTR?(L+1)=Z% DIV  256            )
960 DRAW 600*R*L/readings,Z%            )  plot point on screen
970 L=L+2
980 NEXT N                              )  repeat for all data
1030 IF AA$="N" THEN1070
1040 PROCfile2                          )  store data on disc
1050 PRINT"Data  filed"


1060 PRINT
1070 PRINT"To change gate setting,enter 'G'"'"To change discharge,enter 'Q'"'"else
1080 CHCK=0                                                 )
1090 AC$=INKEY$(0)                                          )
1100PRINT TAB(0,15);"DEPTH READING= ";INT((ADVAL(2))/64)    )
1110T=0:FOR I=1 TO 500:T=T+ADVAL(2)/64                      )
1120 IF AC$="G" OR AC$="Q" THEN 470                         )
1130 IF AC$="S" THEN STOP                                   ) monitor depth
```

```
1140NEXTI:T=T/500                              ) readings until
1141PRINT T,CHCK                               ) table for new
1150IF ABS(T-CHCK)<2 THEN VDU7                 ) gate or Q settings
1160CHCK=T                                     )
1170 GOTO1090                                  )
1180REM*****************************
1190REM  subroutines for disk filing
1200REM****************************

1210 DEF PROCwrite                    PROCEDURE TO WRITE DATA TO DISC

1220 L1=LEN(D$)
1230 FOR I=1 TO L1
1240 E=ASC(MID$(D$,I,1))
1250 BPUT£chan,E
1260 NEXT
1270 BPUT£chan,10
1280 BPUT£chan,10
1290 BPUT£chan,13
1300 ENDPROC
1310 REM****************************

1320 DEF PROCfile1                    PROCEDURE TO WRITE HEADER TO DISC

1330 PROCopenfile
1340 LET D$="£"
1350 PROCwrite
1360 LET D$="DATE OF RUN   "+DATE$
1370 PROCwrite
1380 LET D$="DISCHARGE IN L/S   "+STR$(DISC)
1390 PROCwrite
1400 LET D$="CALIBRATION COEFFICIENT IS  "+STR$(A0%)
1410 PROCwrite
1420 D$="  POS0 DEPTH0 GATE DISCHARGE"
1430 PROCwrite
1440 PROCclosefile
1450 ENDPROC
1460REM*****************************

1470 DEF PROCfile2                    PROCEDURE TO WRITE STORED DATA TO DISC

1480 PROCopenfile
1490 D$=STR$(POS0%)+" "+STR$(DEPTH0)+" "+STR$(GATE)+" "+STR$(DISC)
1500 PROCwrite
1510 FOR I=1 TO L STEP 20
1520 FOR K=I TO 19+I STEP 2
1530 Z%=DTASTR?(K-1)+256*DTASTR?K
1540 FOR J=1 TO LEN(STR$(Z%))
1550 Z=ASC(MID$(STR$(Z%),J,1))
1560 BPUT£chan,Z
1570 NEXT J
1580 BPUT£chan,32
1590 NEXT K
1600 BPUT£chan,10
1610 BPUT£chan,13
1620 NEXT I
1630 D$="999 999 999 999"
1640 PROCwrite
1650 PROCclosefile
```

```
1660 ENDPROC
1670REM******************************
```

```
1680DEF PROCnewfile
```
PROCEDURE TO CREATE NEW DISC FILE

```
1690INPUT TAB(0,3)"ENTER FILENAME  "N$
1700IF LEN(N$)>7 THEN 1690
1710$filename=N$
1720CALL blnkfile
1730chan=?fchan
1740fptr=PTR£chan
1750PRINT£chan,fptr
1760fptr=PTR£chan
1770PTR£chan=0
1780PRINT£chan,fptr
1790FOR X=1 TO 20000
1800BPUT£chan,255
1810NEXT
1820CALL closefile
1830ENDPROC
1840REM******************************
```

```
1850DEF PROCopenfile
```
PROCEDURE TO OPEN DISC FILE

```
1860 PRINT
1870INPUT TAB(0,1)"ENTER FILENAME  "N$
1880IF LEN(N$)>7 THEN 1870
1890$filename=N$
1900CALL openfile
1910chan=?fchan
1920IF chan=0 THEN PROCclosefile
1930PTR£chan=0
1940INPUT£chan,fptr
1950PTR£chan=fptr
1960ENDPROC
1970REM******************************
```

```
1980DEF PROCclosefile
```
PROCEDURE TO CLOSE DISC FILE

```
1990fptr=PTR£chan
2000PTR£chan=0
2010PRINT£chan,fptr
2020CALL closefile
2030ENDPROC
2040REM******************************
```

```
2050 DEF PROCparameter
```
UNIT 4 - PROCparameter

```
2060CLS
2070IF NOT(AA$="") THEN2220
2080PRINT TAB(0,0)"Plot curves rel. to floodplain(R)"'"or absolute(A)"
2090REPEAT:PLT$=INKEY$(0):UNTIL PLT$="R" OR PLT$="A"
2100 PRINT TAB(0,0)"Store data on disk today?,y/n      "'"                  "
2110 AA$=INKEY$(0)
2120 IF AA$="Y" THEN 2150
2130 IF AA$="N" THEN CLS:GOTO2300
2140 GOTO2110
2150 PRINT TAB(0,1)"Open new file,y/n"
2160 AB$=INKEY$(0)
2170 IF AB$="Y" THEN 2200
```

) requests on startup-
) plot rel. to f.p. or m.c.
) store data on disc
) open new file
) date,calibration coeff.

```
2180 IF AB$="N" THEN 2210                  ) subsequent requests-
2190 GOTO2160                              ) discharge,gate setting
2200 PROCnewfile                           ) Y-coord. at start
2210CLS                                    ) depth of water at start
2220 IF AD$="S" THEN 2260
2230 IF AC$="Q" THEN 2270
2240 IF AC$="G" THEN 2300
2250 INPUT TAB(0,4)"DATE e.g. 3/1/85  ";DATE$
2260 INPUT TAB(0,5)"CALIBRATION COEFFICIENT (UNITS/MM) ";A0%
2270 INPUT TAB(0,6)"DISCHARGE (L/S)  ";DISC
2280 IF AD$="S" OR AC$="Q" THEN2300
2290 PROCfile1
2300 INPUT TAB(0,7)"GATE SETTING  ";GATE
2310 INPUT TAB(0,8)"POSITION OF STATION AT START(MM)"'"(Y=1500,PREFERRED) ";POS0%
2320 INPUT TAB(0,10)"DEPTH AT START POSITION(MM) ";DEPTH0
2330 PRINT TAB(0,12)"Correct values?"
2340A$=INKEY$(0)
2350IF A$=CHR$(&0D) THEN2400
2360IF A$="N" AND AC$="Q" THEN CLS:GOTO2270
2370IF A$="N" AND AC$="G" THEN CLS:GOTO2300
2380IF A$="N" AND AC$="" THEN CLS:GOTO2250
2390GOTO2340
2400 AD$=""
2410ENDPROC
2420REM****************************

2430 DEF PROCprobeset                      UNIT 2 - PROCprobeset

2440dist?2=200:dist?1=200:?dist=200        ) resets probe head in X or
2450?steps=255                             ) Y direction before start of run
2460CALL start
2470CLS
2480PRINT TAB(3,0)"SETTING CARRIAGE TO START POSITION"
2490PRINT TAB(6,2)"Horizontal-X or -Y stepper?"
2500PRINT TAB(10,3)"Return to Continue"
2510REPEAT
2520L=GET
2530UNTIL L=88 OR L=89 OR L=&0D
2540IF L=89 THEN2630 ELSE IF L=&0D THEN2830
2550PRINT TAB(0,5)"For motor direction"'"Enter L-left or R-right"
2560?delay=150
2570delay?1=01
2580REPEAT
2590K=GET
2600IF K=76 THEN CALL on1:GOTO2710
2610IF K=82 THEN CALL off1:GOTO2710
2620UNTIL K=76 OR K=82
2630PRINT TAB(0,5)"For motor direction"'"Enter U-up or D-down"
2640?delay=150
2650delay?1=0
2660REPEAT
2670K=GET
2680 IF K=85 THEN CALL on2:GOTO2710
2690IF K=68 THEN CALL off2:GOTO2710
2700UNTIL K=68 OR K=85
2710PRINT TAB(0,7)"Motor "CHR$(L)" called in ";CHR$(K);" Direction."
2720PRINT TAB(0,8)"Start?"
2730REPEAT UNTIL GET=&0D
2740PRINT TAB(0,11)"RESETTING PROBE TO START POSITION"
```

```
2750PRINT TAB(0,9)"To stop press space bar"
2760IF L=88 THEN CALL pulse11
2770IF L=89 THEN CALL pulse22
2780PRINT TAB(0,11)"Restart same motor? Otherwise Quit"
2790REPEAT V$=INKEY$(0)
2800IF V$=CHR$(&0D) THEN 2460
2810IF V$="Q" THEN 2830
2820UNTIL FALSE
2830 ENDPROC
2840 REM****************************
```

```
2850DEF PROCrun                                    UNIT 5 - PROCrun

2860DIST=(6500-POS0%)*25.65
2870?dist=DIST MOD 256                             ) sets length of run
2880AA=DIST DIV 256                                ) given in PROCparameter
2890dist?1=AA MOD 256                              ) starts stepper motors
2900dist?2=AA DIV 256
2910
2920CALL start
2930CLS
2940 CALL off2
2950PRINT TAB(0,5)"Start?"
2960REPEAT UNTIL GET=&0D
2970PRINT TAB(10,8)"PROGRAMME RUN STARTED"
2980PRINT TAB(0,5)"            To stop press space bar"
2990CALL pulse22
3000PRINT TAB(3,8)"Store data? To scrap and re-run 'S'"
3010REPEAT AD$=INKEY$(0)
3020UNTIL NOT(AD$="")
3030ENDPROC
3040 REM****************************
```

```
3050 DEF PROCset                                   UNIT 3 - PROCset

3060CLS
3070PRINT TAB(0,0)"SETTING UP INITIAL PARAMETERS FOR RUN"
3080 PRINT TAB(0,2)"Steps between unaveraged reading x
3090 PRINT TAB(0,3)"Default is 150"
3100INPUT TAB(0,4);RD                              ) sets up RD steps/rdg
3110IF RD=0 THEN RD=150                            ) and SR stepping rate
3120?steps=RD
3130PRINT TAB(0,6)"Stepping rate? (1-10)"
3140PRINT TAB(0,7)"Default is 5"
3150INPUT TAB(0,8);SR
3160SR=SR*30
3170IF SR=0 THEN SR=150
3180?delay=SR MOD 256
3190delay?1=SR DIV 256
3200 ENDPROC
3210REM*******************************
3220DEF PROCintro
3230PRINT TAB(12,10)"PROGRAMME DPBAS"
3240PRINT TAB(0,12)"AUTOMATIC LONG PROFILE DATA COLLECTION"
3250PRINT TAB(7,14)"OCTOBER 1985 D.J. SEARLE"
3260PRINT TAB(10,16)"Return to continue"
3270REPEAT
3280A$=INKEY$(0)
3290IF A$=CHR$(&0D) THEN3310
```

```
3300UNTIL TIME=TIME+1500
3310CLS
3320PRINT TAB(0,4)"Programme to run an automatic"'"data collection facility.
3330PRINT TAB(10,16)"Return to continue"
3340REPEAT
3350A$=INKEY$(0)
3360 IF A$=CHR$(&0D) THEN3380
3370UNTIL TIME=TIME+1500
3380CLS
3390ENDPROC
3400REM***************************
```

UNIT 1 - PROCoptions

```
3410DEF PROCoptions

3420PRINT TAB(1,2);CHR$(141)"    Choose options to continue"
3430PRINT TAB(1,3);CHR$(141)"    Choose options to continue"
3440PRINT TAB(5,8)"Begin new set of runs     -  1"
3450PRINT TAB(5,11)"Continue runs from break :"
3460PRINT TAB(5,12)"Collecting data on disk  -  2"
3470PRINT TAB(5,13)"VDU runs only            -  3"
3480PRINT TAB(5,16)"Terminate programme      -  4"
3490K=GET
3500 IF K=49 THEN 3600
3510IF K=50 THEN AA$="Y":AD$="S":GOTO3550
3520IF K=51 THEN AA$="N":AD$="S":GOTO3550
3530IF K=52 THEN STOP
3540GOTO3490
3550CLS
3560PRINT TAB(0,0)"Plotting relative to floodplain(R)"'"or absolute(A)"
3570 PLT$=INKEY$(0)
3580IF PLT$="A" OR PLT$="R" THEN3600
3590GOTO3570
3600CLOSE £0
3610ENDPROC
```

PROGRAMME LISTING FOR - LONGASM

```
10REM*********************************
20REM LONGASM  OCTOBER 1985  D.J. SEARLE
30REM MACHINE CODE PROGRAMME ASSEMBLED INTO LONGMC
40REM IN CONJUNCTION WITH LONGBAS
50REM**********************************
60 MODE7                                    )
70 PROG=&1A00                               )
80 Workspace=&7800                          )
90 PORTB=&FE60                              )
100 DDRB=&FE62                              )
110 OSFIND=&FFCE                            )
120 OSBYTE=&FFF4                            )
130 ADPTR=&70                               )
140 PT=&4000                                )
150 HIMEM=PT                                )
160 DTASTR=PT+50                            )  name address locations
170 delay=PT                                )
180 ctr=PT+2                                )
190 Ref=PT+4                                )
200 Check=PT+6                              )
210 cntr=PT+8                               )
220 steps=PT+9                              )
230 filename=PT+10                          )
240 fchan=PT+20                             )
250 eflag=PT+21                             )
251dist=PT+22                               )
260REM**************************
270 FOR I%=4 TO 6 STEP 2
280 P%=PROG
290 O%=Workspace
300 [OPT I%
310 .start     LDA £&FF                     ) set user port to output
320            STA DDRB                     ) mode
330            LDA  £DTASTR  MOD  256       )
340            STA ADPTR                    )  set memory location
350            LDA £DTASTR DIV 256          )  pointer to base
360            STA ADPTR+1                  )  address
370            LDA £&01
380            STA cntr
390            RTS
400Ω routines,off/on-direction of
410Ω motor drives
420Ω
430 .on1       LDA £&01                     )
440            ORA PORTB                    )
450            STA PORTB                    )
460            RTS
470.off1       LDA £&FE                     )
480            AND PORTB                    )
490            STA PORTB                    ) set direction of steppers
500            RTS                            called as required
510.on2        LDA £&02                     ) from LONGBAS
520            ORA PORTB                    )
530            STA PORTB                    )
540            RTS
550.off2       LDA £&FD                     )
```

```
560             AND PORTB               )
570             STA PORTB               )
580             RTS
590Ω*****************************
600Ω pulsing motor X
610.pulsell
620             LDA £&10
630             ORA PORTB
640             STA PORTB
650             JSR delaysub
660             LDA £&EF
670             AND PORTB
680             STA PORTB
690             JSR delaysub
700             JSR readadc
710             JSR inkey
720             CMP £&20
730             BEQ endplsll
740Ω check datastore is full
750             LDA ADPTR+1
760             CMP £&55
770             BEQ endplsll
780             JMP pulsell
790.endplsll    RTS
800Ω*****************************
```

UNIT 1

```
820.pulse22
830             LDA £&20                )
840             ORA PORTB               )  pulsing sequence
850             STA PORTB               )
860             JSR delaysub               delay
870             LDA £&DF                )
880             AND PORTB               )  pulsing sequence
890             STA PORTB               )
900             JSR delaysub               delay

910             JSR readadc                read ADC
920             JSR inkey                  check if <ESC> pressed
930             CMP £&20
940             BEQ endpls22
```

UNIT 4

```
941             DEC dist:BNE pulse22                            )
942             LDA £0:CMP dist+1:BEQ next                      )  traverse
943             DEC dist+1:LDA £&FF:STA dist:JMP pulse22        )  length
944.next        LDA £0:CMP dist+2:BEQ endpls22                  )  counter
945             DEC dist+2:LDA £&FF:STA dist+1:STA dist         )


946             JMP pulse22
960.endpls22    LDY £10                         )
961.end         LDA £7:JSR &FFEE:DEY:BNE end    )  beep to signal end
962             RTS                             )  return to LONGBAS
970Ω****************************

990.delaysub
```

DELAY ROUTINE - delaysub

```
1000          LDA delay
1010          STA ctr
1020          LDA delay+1
1030          STA ctr+1
1040          LDA £&00
1050.loop
1060          DEC ctr
1070          BNE loop
1080          CMP ctr+1
1090          BEQ enddly
1100          DEC ctr+1
1110          JMP loop
1120.enddly   RTS
1130Ω****************************
```

UNIT 3
ESCAPE PRESSED ROUTINE
- inkey

```
1150.inkey

1160          LDX £&00
1170          LDY £&00
1180          LDA £&81
1190          JSR OSBYTE
1200          CPY £&1B
1210          BEQ escape
1220          CPY £&00
1230          BNE nokey
1240          TXA
1250          RTS
1260.escape
1270          LDA £&7E
1280          JSR OSBYTE
1290          LDA £&1B
1300          RTS
1310.nokey
1320          LDA £&00
1330          RTS
1340Ω****************************
```

UNIT 2
READ ADC ROUTINE - readadc

```
1360.readadc

1370          DEC cntr
1380          BNE endread
1390          LDA steps
1400          STA cntr
1410          LDA £&80
1420          LDX £&02
1430          JSR OSBYTE
1440          TYA
1450          LDY £&01
1460          STA (ADPTR),Y
1470          DEY
1480          TXA
1490          STA (ADPTR),Y
1500.incptr
1510          CLC
1520          LDA £&02
1530          ADC ADPTR
1540          STA ADPTR
1550          LDA £&00
1560          ADC ADPTR+1
```

```
1570          STA ADPTR+1
1580.endread  RTS
1590Ω
1600.blnkfile  LDA £&80                  )
1610           LDX £filename MOD 256     )
1620           LDY £filename DIV 256     )
1630           JSR OSFIND                )
1640           STA fchan                 )
1650           RTS                       )
1660Ω                                    )
1670.openfile  LDA £&C0                  )
1680           LDX £filename MOD 256     )  file handling routines
1690           LDY £filename DIV 256     )  called as required
1700           JSR OSFIND                )  from LONGBAS
1710           STA fchan                 )
1720           RTS                       )
1730Ω                                    )
1740.closefile LDA £&00                  )
1750           LDY fchan                 )
1760           JSR OSFIND                )
1770           RTS                       )
1780Ω
1790]NEXT I%
1800REM******************************
1810 *SAVE LONGMC 7800 7A00 1A00 1C00     )  save assembled programme
1820 PRINT"start=&";²start                )  in LONGMC
1830 PRINT"pulse11=&";²pulse11            )
1840 PRINT"pulse22=&";²pulse22            )
1850 PRINT"on1=&";²on1                    )
1860 PRINT"on2=&";²on2                    )  LONGMC variable locations
1870 PRINT"blnkfile=&";²blnkfile          )  required for
1880 PRINT"openfile=&";²openfile          )  linking to LONGBAS
1890 PRINT"closefile=&";²closefile        )
1900 PRINT"off1=&";²off1                  )
1910 PRINT"off2=&";²off2                  )
```

3D-SUITE
UNIT 1
PROGRAMME LISTING - INIT

```
10REMPROGRAMME TO START 3D-SUITE
20REM*****************************
30REM*********INIT*************
40REM***DJ SEARLE**UOB***********
50REM*****OCTOBER 1985***********
60*FX21,0
70MODE7
80PROCintro
90CLS
100PRINT CHR$(141)"    Choose options to continue"
110PRINT CHR$(141)"    Choose options to continue"
120PRINT TAB(3,8)"New coords or alter coords   - 1"
130PRINT TAB(3,10)"Continue with preset coords -  2"
140PRINT TAB(3,12)"Terminate programme          -  3"
150K=GET
160IF K=49 THEN CHAIN"3D.DATA"
170IF K=50 THEN 200
180IF K=51 THEN STOP
190GOTO150
200CLS:PRINT TAB(5,0)"Graphical Description?"
210K=GET:IF K=89 OR K=&0D THEN CHAIN"3D.GRPH"
   ELSEIF K=78 THEN CHAIN"3D.INT"
220GOTO210
230END
240REM******************************
250DEF PROCintro
260PRINT TAB(8,10);CHR$(141);"PROGRAMME  SUITE-3D"
270PRINT TAB(8,11);CHR$(141);"PROGRAMME  SUITE-3D"
280PRINT TAB(5,12)"GENERALISED STEPPER MOVEMENT"
290PRINT TAB(10,13)"AND DATA COLLECTION"
300PRINT TAB(7,15)"OCTOBER 1985 D.J. SEARLE"
310PRINT TAB(10,17)"Return to continue"
320TIME=0
330REPEAT
340A$=INKEY$(0)
350IF A$=CHR$(&0D) THEN370
360UNTIL TIME=1500
370CLS
380 PRINT TAB(0,4)"Programme to move instrument probe in"
    '"any directions and collect data"'"through the ADC channels"
390PRINT TAB(0,9)"Either enter new coord data or use"
   '"existing file DAT.IN"'"appropriate prompts will be given"
400PRINT TAB(10,16)"Return to continue"
410TIME=0
420REPEAT
430A$=INKEY$(0):IF A$=CHR$(&0D) THEN450
440UNTIL TIME=1500
450ENDPROC
```

3D-SERIES
UNIT 2
PROGRAMME LISTNG - 3D.DATA

```
 10REM*********************************:
 20REM PROGRAMME 3D.DATA LATEST ED 1.86
 30REM**********************************
 40MODE7
 50HIMEM=&3000
 60*LOAD DAT.IN 3000
 70A=&4000
 80B=&3000
 90xx=B
100yy=B+100
110zz=B+200
120PRINT CHR$(141)"            MENU"          )
130PRINT CHR$(141)"            MENU"          )
140PRINT TAB(5,8)"New Set of Coords      - 1" )
150PRINT TAB(5,10)"New Start Position    - 2" )list of options
160PRINT TAB(5,12)"Continue With Programme - 3" )
170PRINT TAB(5,14)"Load New File         - 4" )
180K=GET
190K=K-48
200ON K GOTO 820,210,1200,330
210CLS
220PRINT TAB(10,6)"New X   Y   Z"             )
230INPUT TAB(14,8)X,Y,Z                       )
240I=1                                        )
250xx?(I-1)=X MOD256                          )
260xx?(I)=X DIV256                           )new start coord
270yy?(I-1)=Y MOD256                          )
280yy?(I)=Y DIV256                            )
290zz?(I-1)=Z MOD256                          )
300zz?(I)=Z DIV256                            )
310GOTO1060                                   )
320REM***************************
330CLS
340REM Initialise block of data
350FORI=1TO300
360xx?I=0
370NEXT
380PRINT TAB(0,0);CHR$(141);CHR$(136);"Load Disc
        containing coordinate data"
390PRINT TAB(0,1);CHR$(141);CHR$(136);"Load Disc
        containing coordinate data"
400PRINT TAB(13,3);CHR$(141);CHR$(136);"Marked 'BB'"
410PRINT TAB(13,4);CHR$(141);CHR$(136);"Marked 'BB'"
420PRINT TAB(0,10);"Enter view file for conversion"
        '"or return to exit"
430PRINT
440PRINT
450INPUT TAB(0,15)"File to convert  ";FIL$      )
460IF FIL$="" THEN CLS:GOTO1210          ) load data file
470OSCLI"LOAD "+FIL$+" 4000 "                  )
480CLS
490PRINT TAB(0,0);CHR$(141);CHR$(136);"Replace Original Drive Disc Marked"
500PRINT TAB(0,1);CHR$(141);CHR$(136);"Replace Original Drive Disc Marked"
510PRINT TAB(13,3);CHR$(141);CHR$(136);"3D-SERIES"
```

```
520PRINT TAB(13,4);CHR$(141);CHR$(136);"3D-SERIES"
550REM****************************
560 K=0                                         )
570I=1                                          )
580dataptr=0                                    )
590D$="":chr$=""                                )
600REPEAT                                       )
610D$=D$+chr$                                   )
620chr=dataptr?A                                )
630chr$=CHR$(chr)                               )
640dataptr=dataptr+1                   ) data in ASCII format
650 UNTIL chr<&21                      ) read and convert
660X=VAL(D$)                           ) store in memory
670IF X=999 THEN 1051                           )
680K=K+1                                        )
690IF K=1 THEN720                               )
700IF K=2 THEN740                               )
710IF K=3 THEN760                               )
720xx?(I-1)=X MOD256                            )
730xx?(I)=X DIV256:GOTO780                      )
740yy?(I-1)=X MOD256                            )
750yy?(I)=X DIV256:GOTO780                      )
760zz?(I-1)=X MOD256                            )
770zz?(I)=X DIV256                              )
780IF K=3 THEN 790 ELSE 800                     )
790K=0:I=I+2                                    )
800GOTO590                                      )
810REM**********************
820CLS
830REMInitialise block of data
840FORI=1TO300
850xx?I=0
860NEXT
870REM*************************
880PRINT TAB(6,6)"Enter X,Y,Z coords in mm"      )
890PRINT TAB(4,7)"Return for new line, Q to quit"     )
900PRINT TAB(6,9)"       X    Y    Z"              )
910I=1                                             )
920T=(I+1)/2+9                                     )
930INPUT TAB(12,T);X,Y,Z                           )
940xx?(I-1)=X MOD 256                              )
950xx?(I)=X DIV 256                                )
960yy?(I-1)=Y MOD 256                  ) input new coords
970yy?(I)=Y DIV 256                                )
980zz?(I-1)=Z MOD 256                              )
990zz?(I)=Z DIV 256                                )
1000I=I+2                                          )
1010A$=INKEY$(0)                                   )
1020IF A$="Q" THEN 1060                            )
1030IF A$=CHR$(&0D) THEN 920                       )
1040GOTO1010                                       )
1050REM*************************
1051PRINT TAB(10,15)"Return To Continue"
1052REPEAT:UNTIL GET=&0D
1060CLS
1070PRINT TAB(5,0)"Save To Backup File?        "
1080 K=GET
1081 IF K=78 THEN 1130 ELSE IF K=89 OR K=&0D THEN 1090
1082 GOTO1080
```

```
1090INPUT TAB(5,0)"DATA FILE NAME     ";FIL$          )
1100PRINT TAB(5,0)"Saving Data To     ",FIL$          )
1110OSCLI "SAVE "+FIL$+" 3000 312C"           ) save data to
1120PRINT TAB(5,0)"Saving Data To  DAT.IN"    ) backup file
1130OSCLI "SAVE DAT.IN 3000 312C"                     )
1140GOTO1200
1150CLS
1160INPUT TAB(5,0)"DATA FILE NAME      ";FIL$          )
1170OSCLI "LOAD "+FIL$+" 3000"                 ) save data to
1180PRINT TAB(5,0)"Saving Data To      ",FIL$  ) DAT.IN
1190OSCLI "SAVE DAT.IN 3000 312C"                      )
1200CLS
1210PRINT TAB(5,0);"  Run stepper programme?"
1220K=GET:IFK=78 THEN STOP ELSEIF K=89 THEN 1230:GOTO1220
1230PRINT TAB(7,0);" Graphics Description?"
1240K=GET:IFK=78 THEN CHAIN"3D.INT" ELSEIF K=89 THEN CHAIN"3D.GRPH"
1250GOTO1240
1260STOP
```

3D-SUITE
UNIT 3
PROGRAMME LISTING - 3D.GRPH

```
1*******************************
2REM 3D.GRPH  DJ SEARLE  1986
3*******************************
10MODE0
20*LOAD PP1 3000                ) load graphics screens
30*LOAD PP2 4A0A                ) into shadow RAM
40*LOAD PP3 65F6                )
50PRINT TAB(20,5)"LINE DRAWING OF FLUME AND INST CARRIAGE"
60PRINT TAB(20,6)"        X Y Z ORDINATES INCLUDED            "
70*XSWAP V.65F6 8000 P.3000     ) swap PP1 onto screen
80PROCchge
90*LOAD PP4 3000                ) load PP4 into shadow RAM
100PRINT TAB(17,5)"ISOMETRIC PLOT OF WATER SURFACE BETWEEN    "
110PRINT TAB(17,6)"            4500 < Y < 6500           "
120PRINT TAB(22,8)"  OVERALL VIEW - PICTURE ONE     "
130*XSWAP V.65F6 8000             ) swap PP2 onto screen
140PROCchge
150PRINT TAB(22,8)"  INITIAL ZOOM - PICTURE TWO     "
160*XSWAP V.65F6 8000             ) swap PP3 onto screen
170PROCchge
180PRINT TAB(17,5)"CROSS-SECTION PROFILE OF FLOW AT STATION    "
190PRINT TAB(26,6)"          Y=6000                           "
200PRINT TAB(22,8)"                                     "
210*XSWAP V.65F6 8000 P.3000      ) swap PP4 onto screen
220PROCchge
230*XSWAP P.3000 4A09 P.4A0A      ) switch graphics in
240*XSWAP P.4A0A 65F5 P.65F6      ) shadow RAM to repeat
250PRINT TAB(17,5)"LINE DRAWING OF FLUME AND INST CARRIAGE    "
260PRINT TAB(17,6)"        X Y Z ORDINATES INCLUDED          "
270PRINT TAB(22,8)"                                     "
280*XSWAP V.65F6 8000 P.3000       ) swap PP1 onto screen
290PROCchge
300GOTO100
310DEF PROCchge
320PRINT TAB(26,0)"Return to change picture"
330PRINT TAB(22,1)"Q to quit graphics and continue"
340K=GET
350IF K=81 THEN PAGE=&2A00:CHAIN "3D.BAS"
360IF K=&0D THEN ENDPROC
370GOTO340
380ENDPROC
```

3D-SUITE
UNIT 4
PROGRAMME LISTING - 3D.INT

```
10REMPROGRAMME TO INPUT PARAMETERS
20REMFOR 3D PROGRAMME
30REM*********3D.INT**************
40REM***DJ SEARLE***OCTOBER1985****
50REM******************************
60*FX21,0
70MODE7
80HIMEM=&7700
90REM aread placed above any
      overwriting from subsequent programmes
100REM relocated to &3500 during execution of 3D.RUN
110aread=&7B50
120PRINT TAB(5,0);"Enter Parameters for Run?"
130K=GET
140IF K=89 OR K=&0D THEN170
150IF K=78 THEN 710
160GOTO130
170FORI=1TO150
180aread?I=&20
190NEXT
200CLS
210PRINT TAB(4,0);CHR$(141);"Series/Run Parameters"
220PRINT TAB(4,1);CHR$(141);"Series/Run Parameters"
230 PRINT TAB(0,3)"DISC - discharge in litres per second"
240PRINT TAB(0,5)"GATE - weir gate setting"
250PRINT TAB(0,7)"SERIES - series number"
260PRINT TAB(0,9)"RUN - run number"
270PRINT TAB(0,11)"CROSS-SECTION - position along y-axis"
280PRINT TAB(7,13)"Enter parameters for run"
290INPUT TAB(0,17)"DISCHARGE = ";DISC
291 DISC=INT(DISC*100)
300INPUT TAB(0,18)"GATE = ";GATE
310INPUT TAB(0,19)"SERIES = ";SERIES
320INPUT TAB(0,20)"RUN = ";RN
330INPUT TAB(0,21)"CROSS-SECTION = ";XSECT
340PRINT TAB(8,23)"Are these correct?"
350K=GET:IF K=89 OR K=&0D THEN360 ELSE IF K=78 THEN200:GOTO350
360CLS
370PRINT TAB(4,0);CHR$(141);"Calibration parameters"
380PRINT TAB(4,1);CHR$(141);"Calibration parameters"
390PRINT TAB(0,3)"ADT0,ADTCAL1-
          from programme ADVAL"'"giving operational
          parameters for the "'"angular displacement transducer."
400 PRINT TAB(0,7)"RATEPT-
          maximum working range"'"of the pressure transducer."
410PRINT TAB(0,10)"PTCALIB - ADC reading for 5volt PT input"
420PRINT TAB(0,12)"DSTBTM,DSTTP-
          dist. hi/lo probe range"'"from bed and surface of f/p"
430PRINT TAB(0,15)"Enter parameters for instruments"
440PRINT TAB(0,16)"Default in brackets:"
450INPUT TAB(0,17)"ADT0(500)units= ";ADT0
460INPUT TAB(0,18)"ADTCAL1(800)units/180deg= ";ADCL1
470INPUT TAB(0,19)"RATEPT(20)mm.H20= ";RATPT
480INPUT TAB(0,20)"PTCALIB5(1118)= ";PTCL1
```

```
490INPUT TAB(0,21)"DSTBTM(1)= ";PTCL2
500INPUT TAB(0,22)"DSTTP(5)= ";PTCL3
510PRINT TAB(8,23)"Are these correct?"
520K=GET:IF K=89 OR K=&0D THEN530 ELSE IF K=78 THEN360:GOTO520
530IF ADT0=0 THEN ADT0=500
540IF ADCL1=0 THEN ADCL1=800
550ADCL2=1
560IF RATPT=0 THEN RATPT=20
570IF PTCL1=0 THEN PTCL1=1118
580PTCL2=2
590A$="DISCHARGE:GATE:SERIES:RUN:CROSS SECTION"
600PROCconvert
610A$=STR$(DISC)+" "+STR$(GATE)+
   " "+STR$(SERIES)+" "+STR$(RN)+" "+STR$(XSECT)
620PROCconvert
630A$="ADT0:ADT1:RATEPT:PTCALIB:DSTBTM:DSTTP:SECTIONS"
640PROCconvert
650A$=STR$(ADT0)+" "+STR$(ADCL1)+
   " "+STR$(RATPT)+" "+STR$(PTCL1)+" "+STR$(PTCL2)+" "+STR$(PTCL3)
660L=LEN(A$)
670FOR I=1 TO L
680aread?(I-1)=ASC(MID$(A$,I,1))
690NEXTI
700aread=aread+L
710PAGE=&2A00
720CHAIN"3D.BAS"
730REM*****************************:
740DEF PROCconvert
750L=LEN(A$)
760FOR I=1 TO L
770aread?(I-1)=ASC(MID$(A$,I,1))
780NEXTI
790aread=aread+L
800aread?0=&0A
810aread?1=&0D
820aread=aread+2
830ENDPROC
```

3D-SUITE
UNIT 5
PROGRAMME LISTING - 3D.BAS

```
10REMPROGRAMME FOR 3D STEPPER PROGRAMME
20REMRUNS WITH 3D.MC
30REM**********3D.BAS*****************
40REM****DJ SEARLE***OCTOBER1985*******
50REM*********************************
60MODE0
70VDU 28,0,31,0,79                    )
80A=&2500                             )
90B=&7700                             )
100HIMEM=B                            )
110*LOAD 3D.MC 1A00                   )  *load m/code prog.
120*LOAD DAT.IN 2500                  )  load data file
130C=&1A17                            )
140xx=A                               )
150yy=A+100                           )
160zz=A+200                           )
170ddx=A+300                          )
180stpx=B                             )
190stpy=B+100                         )
200stpz=B+200                         )
210minj=B+300                         )
220derx=B+400                         )
230dery=B+500                         )
240derz=B+600                         ) name address locs
250signx=B+700                        )
260signy=B+750                        )
270signz=B+800                        )
280signdx=B+850                       )
290signdy=B+900                       )
300signdz=B+950                       )
310cycles=B+1000                      )
320moves=C                            )
330delay=C+1                          )
340delayrd=C+3                        )
350average=C+16                       )
360AD=0
370HH=0
380KK=0
390REM******************************
400REM Initialise data to zero
410FORI=1TO1000:stpx?I=0:NEXT
411FORI=1TO300:ddx?I=0:NEXT
420REM******************************
430DIM PS%(3,50),DIFF%(3,50),MIN%(50),STP%(3,50),TT%(3,50)
440DIM ERX%(50),ERY%(50),ERZ%(50)
450DIM SIGNDX(50),SIGNDY(50),SIGNDZ(50),CYCLES(50)
460REM*********************************
470PRINT TAB(28,4);"      COORDS(MM)"
480PRINT TAB(28,5);"X          Y          Z"
490PRINT TAB(28,6);"-------------------"
500J=0
510FORI=1TO100STEP2
520J=J+1
530PS%(1,J)=xx?(I-1)+xx?I*256      )
```

```
540PS%(2,J)=yy?(I-1)+yy?I*256     ) read coord data into arrays
550PS%(3,J)=zz?(I-1)+zz?I*256     )
560IF PS%(1,J)=0 AND PS%(3,J)=0 AND PS%(2,J)=0 THEN N=J-1:GOTO0610
570IF J<25 THEN 580 ELSEIF J>=25 THEN 590
580PRINT TAB(0,J+6),PS%(1,J),PS%(2,J),PS%(3,J):GOTO0600
590PRINT TAB(40,J+6-24),PS%(1,J),PS%(2,J),PS%(3,J):GOTO0600
600NEXT
610PRINT TAB(0,0)"Hardcopy of X,Y,Z coordinates?"
620K=GET
630IFK=78 THEN750
640IF K=89 OR K=&0D THEN660
650GOTO0620
660VDU2
670VDU21
680PRINT "                 COORDS(MM)"
690PRINT"          X           Y          Z"
700PRINT
710FORI=1TO N
720PRINTPS%(1,I),PS%(2,I)PS%(3,I):NEXT
730VDU6
740VDU3
750REM convert coords to step values
760FORJ=1TON:FORI=1TO3STEP2              )
770PS%(I,J)=PS%(I,J)*48/1.25:NEXTI       ) convert coords to
780PS%(2,J)=PS%(2,J)*24.88               ) step values in X,Y,Z
790NEXTJ                                 ) directions
800REM*********************************
810REM Obtain difference between values
820FORJ=1TON:FORI=1TO3               )
830DIFF%(I,J)=PS%(I,J+1)-PS%(I,J)    ) calculate steps in X,Y,Z
840NEXT:NEXT                         ) between coordinates
850REM*********************************
860REM find least steps in X,Y or Z
870FORJ=1TON-1                                                    )
880D1%=ABS(DIFF%(1,J)):D2%=ABS(DIFF%(2,J)):D3%=ABS(DIFF%(3,J))  )
890IF D1%=0 AND D2%=0 AND D3%=0 THEN CHAIN "3D.DATA"              )
900 IF D1%=0 AND D2%=0 THEN MIN%(J)=D3%:GOTO0970                  )
910 IF D1%=0 AND D3%=0 THEN MIN%(J)=D2%:GOTO0970        ) find least
920 IF D2%=0 AND D3%=0 THEN MIN%(J)=D1%:GOTO0970        ) steps in X,
930 IF D1%>0 THEN MIN%(J)=D1% ELSE MIN%(J)=D2%          ) Y or Z
940 IF D1%<D2% AND D1%<D3% AND D1%>0 THEN MIN%(J)=D1%:GOTO0970   )
950 IF D2%<D3% AND D2%<D1% AND D2%>0 THEN MIN%(J)=D2%:GOTO0970   )
960 IF D1%<D3% AND D1%<D2% AND D3%>0 THEN MIN%(J)=D3%:GOTO0970   )
970NEXT                                                           )
980REM*********************************
990REM find integer ratios between X,Y,Z steps                    )
1000INPUT TAB(0,1)"Enter K to change step ratio(default=50)";K   )
1010IF K=0 THEN K=50                                 ) find
1020FORJ=1TON-1:MIN%(J)=MIN%(J)/K:FORI=1TO3          ) approximate
1030IFMIN%(J)=0THENMIN%(J)=1                         ) integer
1040STP%(I,J)=DIFF%(I,J)/MIN%(J)+0.5                 ) ratios
1050NEXTI                                              )
1060NEXTJ                                              )
1070REM*********************************
1080REM reduce steps to smallest factor         )
1090FORK=1TO2:FORJ=1TON-1:FORNUM=10TO1STEP-1    )
1100IF STP%(1,J)MODNUM=0 AND STP%(2,J)MODNUM=0)
AND STP%(3,J)MODNUM=0 THEN 1120                 ) reduce to smallest
1110NEXTNUM                                     ) common denominator
```

```
1120FORI=1TO3:STP%(I,J)=STP%(I,J)/NUM:NEXTI:   )
MIN%(J)=MIN%(J)*NUM                            )
1130NEXTJ                                      )
1140NEXTK                                      )
1150FOR J=1 TO N
1160IF STP%(1,J)<0 THEN signx?(J-1)=&FE        )
1170IF STP%(1,J)>0 THEN signx?(J-1)=&01        )
1180IF STP%(2,J)<0 THEN signy?(J-1)=&FD        ) calculate direction
1190IF STP%(2,J)>0 THEN signy?(J-1)=&02        ) parameters and store
1200IF STP%(3,J)<0 THEN signz?(J-1)=&FB        )
1210IF STP%(3,J)>0 THEN signz?(J-1)=&04        )
1220NEXT J
1230REM**********************************
1240REM Calculate cycles and dx dy dz
1250REM*********************************
1260PRINT TAB(0,2);"Run motor only?"
1270B$=INKEY$(0)
1280IF B$="Y" THEN 1310
1290IF B$="N" THEN 1350
1300GOTO1270
1310 J=0:FORI=1TON-1:cycles?J=MIN%(I)MOD256
1311 cycles?(J+1)=MIN%(I)DIV256:J=J+2:NEXT
1320FORI=1TON-1:CYCLES(I)=MIN%(I):NEXT
1330H=0:L=1:AVGE=1:GOTO2180
1340REM******************************
1350SC=1.25/48
1360PRINT TAB(0,0)"                              "
1370PRINT TAB(0,1)"
1380PRINT TAB(0,2)"                              "
1390M=0:I=0
1400PRINT TAB(0,0);"Enter parameters for leg
1410FORJ=1TON-1
1420IF J<24 THEN 1430 ELSE 1470
1430 PRINT TAB(0,6+J) ">"
1440PRINT TAB(0,7+J) ">"
1450PRINT TAB(0,5+J) " "
1460GOTO1520
1470PRINT TAB(0,29)" "
1480PRINT TAB(0,30)" "
1490PRINT TAB(40,6+J-24) ">"
1500PRINT TAB(40,7+J-24) ">"
1510PRINT TAB(40,5+J-24) " "
1520D1%=ABS(DIFF%(1,J)):D2%=ABS(DIFF%(2,J)):D3%=ABS(DIFF%(3,J))
1530PRINT TAB(0,1)"                     "
1540PRINT TAB(0,1)"Axis (X,Y,Z)"
1550K=GET
1560IFK=88THEND=D1%:GOTO1600
1570IFK=89THEND=D2%:GOTO1600
1580IFK=90THEND=D3%:GOTO1600
1590GOTO1550
1600IFD=0THENPRINT TAB(20,1)"Illegal axis":GOTO1540
1610PRINT TAB(20,1)"                   "
1620PRINT TAB(0,2);"Approx. Spacing on ";CHR$(K);"-axis mm"
1630INPUT TAB(35,2);SP
1640IF SP=0 THEN1620 ELSE1650
1650CYCLES=INT((SP*MIN%(J))/(SC*D))
1660NN=MIN%(J)/CYCLES
1670R=NN-(NN DIV1)
1680IF R>=0.5 THEN AD=1 ELSE AD=0
```

```
1690NN%=NN+AD
1700IF NN%=0 THEN NN%=1
1710DX=D1%*SC*10/NN%
1720DY=D2%*SC*10/NN%
1730DZ=D3%*SC*10/NN%
1740IF K=88 THEN SP=DX/10
1750IF K=89 THEN SP=DY/10
1760IF K=90 THEN SP=DZ/10
1770CYCLES(J)=INT((SP*MIN%(J))/(SC*D))
1780NN=MIN%(J)/CYCLES(J)
1790R=NN MOD 1 - NN
1800IF R=0 THEN 1810 ELSE 1820
1810CYCLES(J)=CYCLES(J)*1.01
1820NN%=MIN%(J)/CYCLES(J)
1830IFNN%=0THEN NN%=1
1840DX=D1%*SC*10/NN%
1850DY=D2%*SC*10/NN%
1860DZ=D3%*SC*10/NN%
1880DX%=DX:DY%=DY:DZ%=DZ
1890PRINT TAB(40,2),DX%/10,DY%/10,DZ%/10
1900NN%=NN%+1
1910IFNN%=2 THEN NN%=0
1920PRINT TAB(0,0);"                                          "
1940PRINT TAB(0,0);"No. of readings =";NN%;" cycles=";CYCLES(J)
1950ddx?I=DX MOD 256              )
1960ddx?(I+1)=DX DIV 256          )  store distance
1970ddx?(I+2)=DY MOD 256          )  between readings
1980ddx?(I+3)=DY DIV 256          )  along X,Y,Z
1990ddx?(I+4)=DZ MOD 256          )
2000ddx?(I+5)=DZ DIV 256          )
2010ddx?(I+6)=NN% MOD 256         )  store no. readings
2020ddx?(I+7)=NN% DIV 256         )  per traverse
2030cycles?M=CYCLES(J)MOD256      )  store no. unit cycles
2040cycles?(M+1)=CYCLES(J)DIV256  )  between reading positions
2050M=M+2
2060I=I+8
2070PRINT TAB(0,1);"                                             "
2080PRINT TAB(0,2);"                                             "
2090NEXT
2100CLS
2110INPUT TAB(16,10);"Delay between readings
          (0.1-..255secs:default=1)";DELAY
2120IF DELAY=0 THEN DELAY=1
2130IF DELAY>1 THEN H=DELAY-1:L=70
2140IF DELAY<=1 THEN H=0:L=DELAY/0.0140
2150INPUT TAB(11,12);"Readings to sample
          2,4,8,16,32,64,128 only (default=4) ";AVGE
2160IF AVGE=0 THEN AVGE=4
2161 TMP=AVGE/2
2162 TMP2=TMP-INT(TMP)
2163IF TMP2=0 THEN 2170
2164PRINT TAB(11,12);"
2165GOTO2150
2170REM*******************************
2180REM print step values
2190REM*******************************
2200CLS
2210PRINT TAB(20,0)"   STPX      STPY      STPZ     MIN%(J)"
2220FORJ=1TON-1
```

```
2230IF J<25 THEN 2240 ELSE 2250
2240PRINT TAB(0,J+2)STP%(1,J),STP%(2,J),STP%(3,J),MIN%(J):GOTO2260
2250PRINT TAB(40,J-23)STP%(1,J),STP%(2,J),STP%(3,J),MIN%(J)
2260NEXT
2270PROCcontinue
2280REM*******************************
2290REM calculate and print stepped positions
2300PRINT TAB(15,0)"          STEPPED POSITIONS"
2310PRINT TAB(15,1)"        X         Y         Z"
2320FORJ=1TON
2330FORI=1TO3
2340TT%(I,1)=PS%(I,1)
2350TT%(I,J+1)=TT%(I,J)+STP%(I,J)*MIN%(J)
2360NEXT
2370IF J<25 THEN2380 ELSE 2390
2380PRINT TAB(0,J+4)TT%(1,J),TT%(2,J),TT%(3,J):GOTO2400
2390PRINT TAB(40,J+2-22)TT%(1,J),TT%(2,J),TT%(3,J)
2400NEXT
2410PROCcontinue
2420REM*******************************
2430FORJ=1TON
2440FORI=1TO3
2450ERX%(J)=TT%(1,J)-PS%(1,J)
2460ERY%(J)=TT%(2,J)-PS%(2,J)
2470ERZ%(J)=TT%(3,J)-PS%(3,J)
2480NEXT:NEXT
2490REM calculate d.errors and signs
2500PRINT TAB(15,0)"     Corr. factors between legs"
2510PRINT TAB(15,1)"      DERX      DERY       DERZ"
2520PRINT
2530J=1
2540FOR I=1 TO N-1
2550DERX%=CYCLES(I)*(ERX%(I+1)-ERX%(I))/MIN%(I)+0.5
2560DERY%=CYCLES(I)*(ERY%(I+1)-ERY%(I))/MIN%(I)+0.5
2570DERZ%=CYCLES(I)*(ERZ%(I+1)-ERZ%(I))/MIN%(I)+0.5
2580IF DERX%<0 THEN signdx?(I-1)=&01          )
2590IF DERX%>0 THEN signdx?(I-1)=&FE          )
2600IF DERY%<0 THEN signdy?(I-1)=&02     ) store direction
2610IF DERY%>0 THEN signdy?(I-1)=&FD     ) of error corrections
2620IF DERZ%<0 THEN signdz?(I-1)=&04          )
2630IF DERZ%>0 THEN signdz?(I-1)=&FB          )
2640IF I<25 THEN2650 ELSE 2660
2650PRINT TAB(0,I+2) DERX%,DERY%,DERZ%:GOTO2670
2660PRINT TAB(40,I+2-22)DERX%,DERY%,DERZ%
2670DERX%=ABS(DERX%)
2680DERY%=ABS(DERY%)
2690DERZ%=ABS(DERZ%)
2700derx?(J-1)=DERX% MOD 256                  )
2710derx?J=DERX% DIV 256                      )
2720dery?(J-1)=DERY% MOD 256             ) store error
2730dery?J=DERY% DIV 256                 ) corrections in X,Y,Z
2740derz?(J-1)=DERZ% MOD 256                  )
2750derz?J=DERZ% DIV 256                      )
2760J=J+2
2770NEXTI
2780PRINT TAB(20,30)"Hardcopy of calculated step values?"
2790K=GET
2800IF K=78 THEN2920
2810IF K=89 OR K=&0D THEN VDU2:VDU21:GOTO2830
```

3D-SUITE
UNIT 6
PROGRAMME LISTING - 3D.RUN

```
10REM***********************************
20REM PROGRAMME 3D.RUN  LATEST ED. 1.86
30REM********D J SEARLE****************
40REM****UNIVERSITY OF BRISTOL*********
50MODE7
60CLS
70HIMEM=&3500
80C=&1A17
90Setup=C+18
100REM move data stored from 3D.INT at 7B50 to 3500
110*XMOVE P.7B50 +83 P.3500
120AREAD=&3583
130TMP=?C
140AREAD?2=(TMP MOD 10)+&30
150TMP=TMP DIV 10
160AREAD?1=(TMP MOD 10)+&30
170?AREAD=(TMP DIV 100)+&30
180AREAD?3=&20
190AREAD?4=&0A
200AREAD?5=&0D
210PRINT TAB(5,2);CHR$(141)"Choose option to continue"
220PRINT TAB(5,3);CHR$(141)"Choose option to continue"
230PRINT TAB(5,6)"Commence programme run -  1"
240PRINT TAB(5,8)"Terminate programme    -  2"
250PRINT TAB(5,10)"Return to original menu-  3"
260K=GET
270IF K<47 OR K>51 THEN 260
280K=K-48
290ON K GOTO 330,720,300
300PAGE=&1A00:CHAIN"INIT"
310REM Initialise //ram
320REM*********************
330CLS
340PRINT TAB(6,15);CHR$(136);"Initialising parallel ram"
350FORI=&3589TO&4500:?I=0:NEXT
360REM*********************
370CLS
380PRINTTAB(0,9)
390BASE=&3500
400S$=""
410 FOR I=0 TO 99:S$=S$+CHR$(BASE?I):NEXT
420PRINT S$
430S$=""
440 FOR I=107 TO 140:S$=S$+CHR$(BASE?I):NEXT
450PRINT S$
460PRINT TAB(6,1)"MACHINE PROGRAMME RUNNING"
470PRINT TAB(12,2)"DO NOT TOUCH"
480PRINT TAB(1,20)"Averaged Velocity and Angles at probe"
490PRINT TAB(5,21)" VELOCITY           ANGLE"
500CALL Setup
510CLS
520PRINT TAB(12,0);CHR$(141)"Run finished"
530PRINT TAB(12,1);CHR$(141)"Run finished"
540PRINT TAB(6,4);CHR$(141)"Choose option to continue"
```

```
550PRINT TAB(6,5);CHR$(141)"Choose option to continue"
560PRINT TAB(3,8)"Save and process data          - 1"
570PRINT TAB(3,10)"Rerun programme-same coords  - 2"
580PRINT TAB(3,12)"Return to original Menu      - 3"
590K=GET
600IF K<49 OR K>51 THEN590
610IFK=49THEN660
620IFK=50THEN CHAIN "3D.BAS"
630IFK=51THEN PAGE=&1A00:CHAIN "INIT"
640IFK=52THEN
650GOTO590
660CLS
680*SAVE DAT.OUT 3500 5500
700PRINT TAB(0,0)"Convert data to ASCII format?"
710K=GET:IFK=78 THEN 720 ELSE 730
720STOP
730PAGE=&1A00
740CHAIN"TFR"
```

3D-SUITE
PROGRAMME LISTING - 3D-ASM

```
 10REM PROGRAMME 3D.ASM   LATEST ED. 25/7/86
 20REM**************************************
 30MODE7
 40aread=&3589                             )
 50A=&2500                                 )
 60xx=A                                    )
 70yy=A+100                                )
 80zz=A+200                                )
 90ddx=A+300                               )
100B=&7700                                 )
110stpx=B                                  )
120stpy=B+100                              )
130stpz=B+200                              )
140minj=B+300                              )
150derx=B+400                              )
160dery=B+500                              )
170derz=B+600                              )
180signx=B+700                             )
190signdx=B+850                            )
200cycles=B+1000                           )
210STPX=&70                                )
220STPY=&72                                )
230STPZ=&74                                )
240MINJ=&76                                )
250DERX=&78                                )
260DERY=&7A                                ) naming address
270DERZ=&7C                                ) locations
280AREAD=&7E                               )
290SIGN=&80                                )
300SIGND=&82                               )
310XX=&84                                  )
320YY=&86                                  )
330ZZ=&88                                  )
340DX=&8A                                  )
350CYCLES=&8C                              )
360PORTB=&FE60                             )
370DDRB=&FE62                              )
380OSBYTE=&FFF4                            )
390FOR OPT%=0 TO 3 STEP 3
400P%=&1A00
410O%=&7300
420[OPT OPT%
430.x       EQUW 0                         ) UNIT 7
440.y       EQUW 0                         )
450.z       EQUW 0                         )
460.dx      EQUW 0                         )
470.dy      EQUW 0                         )
480.dz      EQUW 0                         )
490.cnt     EQUW 0                         )
500.cycl    EQUB 0                         )
510.cych    EQUB 0                         )
520.offsl   EQUB 0                         )
530.offsh   EQUB 1                         )
540.offsbl  EQUB 0                         ) defining and
550.offsb2  EQUB 50                        ) initialising
```

```
560.offsb3  EQUB 100                              ) parameters
570.offsb4  EQUB 0                                ) within programme
580.inkey   EQUB 0                                )
590.moves   EQUB 0                                )
600.delay   EQUW 0                                )
610.delayrd EQUW 0                                )
620.ctr     EQUW 0                                )
630.ctrl    EQUW 0                                )
640.store   EQUW 0                                )
650.temp    EQUW 0                                )
660.templ   EQUW 0                                )
670.channel EQUB 0                                )
680.average EQUB 0                                )
690.reading EQUB 0                                )
700.Setup  ΩSet up initial pointersΩ
710        LDA £stpx MOD 256:STA STPX              )
720        LDA £stpx DIV 256:STA STPX+1            )
730        LDA £stpy MOD 256:STA STPY              )
740        LDA £stpy DIV 256:STA STPY+1            )
750        LDA £stpz MOD 256:STA STPZ              )
760        LDA £stpz DIV 256:STA STPZ+1            )
770        LDA £minj MOD 256:STA MINJ              )
780        LDA £minj DIV 256:STA MINJ+1            )
790        LDA £derx MOD 256:STA DERX              )
800        LDA £derx DIV 256:STA DERX+1            )
810        LDA £dery MOD 256:STA DERY              )
820        LDA £dery DIV 256:STA DERY+1            )
830        LDA £derz MOD 256:STA DERZ              )
840        LDA £derz DIV 256:STA DERZ+1            )
850        LDA £signx MOD 256:STA SIGN             ) setting pointers
860        LDA £signx DIV 256:STA SIGN+1           )
870        LDA £signdx MOD 256:STA SIGND           )
880        LDA £signdx DIV 256:STA SIGND+1         )
890        LDA £aread MOD 256:STA AREAD            )
900        LDA £aread DIV 256:STA AREAD+1          )
910        LDA £xx MOD 256:STA XX                  )
920        LDA £xx DIV 256:STA XX+1                )
930        LDA £yy MOD 256:STA YY                  )
940        LDA £yy DIV 256:STA YY+1                )
950        LDA £zz MOD 256:STA ZZ                  )
960        LDA £zz DIV 256:STA ZZ+1                )
970        LDA £ddx MOD 256:STA DX                 )
980        LDA £ddx DIV 256:STA DX+1               )
990        LDA £cycles MOD 256:STA CYCLES          )
1000       LDA £cycles DIV 256:STA CYCLES+1        )
1010       LDA £&FF:STA DDRB                       ) set user port to
1020Ω                                                output state
1030.Start
1040ΩStore new data in parallel ram from &3000Ω
1050Ω                                                UNIT 8
1060       LDA £&6F:LDX £&81:JSR OSBYTE            ) switch in shadow RAM
1070       LDY £0                                  )
1080       LDA £&FF:STA (AREAD),Y                  )
1090       INY:LDA £&FF:STA (AREAD),Y              )
1100       LDA £2:CLC:ADC AREAD:STA AREAD          )
1110       LDA £0                                  )
1120       ADC AREAD+1:STA AREAD+1                 )
1130       DEY                                     )
1140.Lpl   LDA (XX),Y:STA (AREAD),Y                )
```

```
1150        INY:CPY £2:BEQ Lp2:JMP Lp1              )
1160.Lp2    LDA £2:CLC:ADC AREAD:STA AREAD          )
1170        LDA £0                                  )
1180        ADC AREAD+1:STA AREAD+1                 )
1190        LDA £2:CLC:ADC XX:STA XX                )
1200        LDA £0                                  )
1210        ADC XX+1:STA XX+1                       )
1220        LDY £0                                  )
1230.Lp3    LDA(YY),Y:STA (AREAD),Y                 )
1240        INY:CPY £2:BEQ Lp4:JMP Lp3              )
1250.Lp4    LDA £2:CLC:ADC AREAD:STA AREAD          )
1260        LDA £0                                  )
1270        ADC AREAD+1:STA AREAD+1                 )
1280        LDA £2:CLC:ADC YY:STA YY                )
1290        LDA £0                                  )
1300        ADC YY+1:STA YY+1                       ) store current traverse
1310        LDY £0                                  ) data -X,Y,Zcoord
1320.Lp5    LDA(ZZ),Y:STA (AREAD),Y                 ) at start
1330        INY:CPY £2:BEQ Lp6:JMP Lp5              )
1340.Lp6    LDA £2:CLC:ADC AREAD:STA AREAD          ) dist between rdgs
1350        LDA £0                                  ) directions
1360        ADC AREAD+1:STA AREAD+1                 ) no of rdgs per traverse
1370        LDA  £2:CLC:ADC  ZZ:STA  ZZ             )
1380        LDA £0                                  ) traverse
1390        ADC ZZ+1:STA ZZ+1                       )
1400        LDY £0                                  )
1410.Lp7    LDA(DX),Y:STA (AREAD),Y                 )
1420        INY:CPY £6:BEQ Lp8:JMP Lp7              )
1430.Lp8    LDA(DX),Y:STA (AREAD),Y:STA reading)
1440        INY                                     )
1450        LDA(DX),Y:STA (AREAD),Y                 )
1460        LDA £8:CLC:ADC AREAD:STA AREAD          )
1470        LDA £0                                  )
1480        ADC AREAD+1:STA AREAD+1                 )
1490        LDA £8:CLC:ADC DX:STA DX                )
1500        LDA £0                                  )
1510        ADC DX+1:STA DX+1                       )
1520        LDY £0                                  )
1530        LDA £&FF:STA (AREAD),Y                  )
1540        INY:LDA £&FF:STA (AREAD),Y              )
1550        LDA £2:CLC:ADC AREAD:STA AREAD          )
1560        LDA £0                                  )
1570        ADC AREAD+1:STA AREAD+1                 )
1580        LDA £&6F:LDX £&C0:JSR OSBYTE            ) switch out shadow RAM
1590Ω
1600        DEC moves:BNE Cnt:JMP End               ) check end of run
1610Ω
1620ΩSet minj to next valueΩ
1630.Cnt    LDA reading:BEQ Cnt1:JSR Procadc        ) UNIT 9
1640.Cnt1   LDY offsl:LDA (MINJ),Y:STA cnt          )
1650        LDY offsh:LDA (MINJ),Y:STA cnt+1        ) load total steps in
1660        BNE Reset                               ) traverse
1670        LDA cnt                                 )
1680        BNE Reset                               )
1690        LDA £01: STA cnt                        )
1700Ω
1710.Reset
1720ΩReset directions of stepper motorsΩ        ) UNIT 10
1730        LDY offsbl:LDA (SIGN),Y                 )
```

```
1740        BMI R1                                 )
1750        ORA PORTB:STA PORTB:JMP R2             )
1760.R1     AND PORTB:STA PORTB                    )
1770.R2     LDY offsb2:LDA (SIGN),Y                ) set current dir of
1780        BMI R3                                 ) stepper motors
1790        ORA PORTB:STA PORTB:JMP R4             )
1800.R3     AND PORTB:STA PORTB                    )
1810.R4     LDY offsb3:LDA (SIGN),Y                )
1820        BMI R5                                 )
1830        ORA PORTB:STA PORTB:JMP R6             )
1840.R5     AND PORTB:STA PORTB                    )
1850Ω
1860ΩReset value for cyclesΩ                        UNIT 11
1870.R6     LDY offsl:LDA (CYCLES),Y:STA cycl      ) load no. stepblocks
1880        LDY offsh:LDA (CYCLES),Y:STA cych      ) between readings
1890Ω
1900.Pulse
1910ΩReset x,y,z values for pulsingΩ
1920        LDY offsl                              ) UNIT 12
1930        LDA (STPX),Y:STA x                     )
1940        LDA (STPY),Y:STA y                     )
1950        LDA (STPZ),Y:STA z                     ) load X,Y,Z stepblocks
1960        LDY offsh                              ) equal val. of steps
1970        LDA (STPX),Y:STA x+1                   ) in X,Y,Z directions
1980        LDA (STPY),Y:STA y+1                   ) to move probe in
1990        LDA (STPZ),Y:STA z+1                   ) computed direction
2000Ω
2010ΩBeginning of pulsing routineΩ
2020Ω
2030Ω
2040ΩPulsing motor X
2050.Pls1                                          ) UNIT 13
2060        LDA £0:CMP x:BEQ P2                    )
2070.P1                                            )
2080        LDA £&10:ORA PORTB:STA PORTB           )
2090        JSR Delay                              )
2100        LDA £&EF:AND PORTB:STA PORTB           ) pulse X by stepblock
2110        JSR Delay                              )
2120        DEC x:BNE P1                           )
2130.P2     LDA £0:CMP x+1:BEQ Pls2                )
2140        DEC x+1:LDA £&FF:STA x                 )
2150        JMP P1                                 )
2160Ω
2170ΩPulsing motor Y
2180.Pls2   LDA £0:CMP y:BEQ P4                    )
2190.P3     LDA £&20:ORA PORTB:STA PORTB           )
2200        JSR Delay                              )
2210        LDA £&DF:AND PORTB:STA PORTB           )
2220        JSR Delay                              ) pulse Y by stepblock
2230        DEC y:BNE P3                           )
2240.P4     LDA £0:CMP y+1:BEQ Pls3                )
2250        DEC y+1:LDA £&FF:STA y                 )
2260        JMP P3                                 )
2270Ω
2280ΩPulsing motor Z
2290.Pls3   LDA £0:CMP z:BEQ P6                    )
2300.P5     LDA £&40:ORA PORTB:STA PORTB           )
2310        JSR Delay                              )
2320        LDA £&BF:AND PORTB:STA PORTB           )
```

```
2330        JSR Delay                          ) pulse Z by stepblock
2340        DEC z:BNE P5                       )
2350.P6     LDA £0:CMP z+1:BEQ Endpulse        )
2360        DEC z+1:LDA £&FF:STA z             )
2370        JMP P5                             )
2380Ω
2390ΩCheck values of cycles,minj to continue pulsingΩ
2400Ω
2410.Endpulse                                   UNIT 14
2420        DEC cnt:BEQ C1:JMP C2              ) check end of
2430.C1     LDA cnt+1:BEQ Nextj:DEC cnt+1      ) traverse reached
2440Ω
2450.C2     JSR Inkey:CMP £&1B:BNE C3:JMP End  ) check <ESC> pressed
2460Ω
2470.C3     DEC cycl:BEQ C4:JMP Pulse          ) check if posn to
2480.C4     LDA cych:BEQ Endcycle:DEC cych:    ) read probe reached
2481        JMP Pulse
2490
2500.Endcycle
2510        JSR Procint                        ) correct posn error
2520        DEC reading:BMI E1                 ) check end traverse
2530        JSR Procadc                        ) read ADC
2540.E1     JMP Reset                          ) repeat
2550.Nextj
2560        LDY offsh:LDA (CYCLES),Y:CLC:LSR A )
2561        STA temp+1                         )
2570        LDY offsl:LDA (CYCLES),Y::ROR A    )
2571        STA temp                           ) check for final reading
2580        LDA temp+1:CMP cych:BMI Nextjj     ) at end of traverse
2590        LDA temp:CMP cycl:BMI Nextjj       )
2600        JSR Procint                        )
2610        LDA reading:CMP £1:BNE Nextjj      )
2620        JSR Procadc                        )
2630.Nextjj
2640ΩIncrement offset valuesΩ
2650        LDY offsl:INY:INY:STY offsl        )
2660        LDY offsh:INY:INY:STY offsh        )
2670        LDY offsb1:INY:STY offsb1          ) increment data ptrs
2680        LDY offsb2:INY:STY offsb2          )
2690        LDY offsb3:INY:STY offsb3          )
2700        LDY offsb4:INY:INY:STY offsb4      )
2710Ω
2720        JMP Start                          ) repeat
2730.End
2740        LDA £&6F:LDX £&81:JSR OSBYTE       )
2750        LDY £0                             )
2760        LDA £&FE:STA (AREAD),Y             ) store 'end file'
2770        INY:LDA £&FE:STA (AREAD),Y         ) pointer
2780        LDA £2:CLC:ADC AREAD:STA AREAD     )
2790        LDA £0                             )
2800        ADC AREAD+1:STA AREAD+1            )
2810        LDA £&6F:LDX £&C0:JSR OSBYTE       )
2820.Envelope
2830        EQUD &FC040101                     )
2840        EQUD &0A140A04                     )
2850        EQUD &FB00007F                     )
2860        EQUW &7E7E                         )
2870        LDX £Envelope MOD 256              )
2880        LDY £Envelope DIV 256              ) alarm to signal
```

```
2890        LDA £8:JSR &FFF1                ) operator at
2900.Beep1  EQUD &00010001                  ) end of run
2910        EQUD &00640064                  )
2920Ω.Beep2 EQUD &00010002                  )
2930Ω       EQUD &00640032                  )
2940.Sound  LDX £Beep1 MOD 256              )
2950        LDY £Beep1 DIV 256              )
2960        LDA £7:JSR &FFF1                )
2970Ω        LDX £Beep2 MOD 256             )
2980Ω        LDY £Beep2 DIV 256             )
2990Ω        LDA £7:JSR &FFF1               )
3000        RTS
3010Ω
3020Ω
3030Ω Subroutines
3040Ω
3050Ω Corrections between cycles
                                             UNIT 15
3060.Procint                      POSITION CORRECTION ROUTINE

3070.Derx   LDY offsb1:LDA (SIGND),Y          ) set X direction
3080        BMI I1                            )
3090        ORA PORTB:STA PORTB:JMP I2        )
3100.I1     AND PORTB:STA PORTB               )
3110.I2     LDY offsb4:LDA (DERX),Y:STA dx    )
3120        INY:LDA (DERX),Y:STA dx+1:BNE I3  )
3130        LDA dx:BNE I3                     )
3140        JMP Dery                          )
3150.I3     LDA £&10:ORA PORTB:STA PORTB      )  pulse X motor
3160        JSR Delay                         )  by total steps
3170        LDA £&EF:AND PORTB:STA PORTB      )  for correction
3180        JSR Delay                         )
3190        DEC dx:BNE I3                     )
3200        LDA dx+1:BEQ Dery                 )
3210        DEC dx+1:LDA £&FF:STA dx:JMP I3   )
3220.Dery   LDY offsb2:LDA (SIGND),Y          ) set Y direction
3230        BMI I4                            )
3240        ORA PORTB:STA PORTB:JMP I5        )
3250.I4     AND PORTB:STA PORTB               )
3260.I5     LDY offsb4:LDA (DERY),Y:STA dy    )
3270        INY:LDA (DERY),Y:STA dy+1:BNE I6  )
3280        LDA dy:BNE I6                     )
3290        JMP Derz                          )
3300.I6     LDA £&20:ORA PORTB:STA PORTB      ) pulse Y motor
3310        JSR Delay                         )
3320        LDA £&DF:AND PORTB:STA PORTB      )
3330        JSR Delay                         )
3340        DEC dy:BNE I6                     )
3350        LDA dy+1:BEQ Derz                 )
3360        DEC dy+1:LDA £&FF:STA dy:JMP I6   )
3370.Derz   LDY offsb3:LDA (SIGND),Y          ) set Z direction
3380        BMI I7                            )
3390        ORA PORTB:STA PORTB:JMP I8        )
3400.I7     AND PORTB:STA PORTB               )
3410.I8     LDY offsb4:LDA (DERZ),Y:STA dz    )
3420        INY:LDA (DERZ),Y:STA dz+1:BNE I9  )
3430        LDA dz:BNE I9                     )
3440        JMP Endint                        )
3450.I9     LDA £&40:ORA PORTB:STA PORTB      ) pulse Z motor
```

```
3460        JSR Delay                             )
3470        LDA £&BF:AND PORTB:STA PORTB          )
3480        JSR Delay                             )
3490        DEC dz:BNE I9                         )
3500        LDA dz+1:BEQ Endint                   )
3510        DEC dz+1:LDA £&FF:STA dz:JMP I9       )
3520.Endint
3530        RTS
3540Ω
3550ΩRead adc channels                              UNIT 16
3560.Procadc LDA £7:JSR &FFEE                       READ ADC ROUTINE
3570.Trans
3580        LDA temp:STA channel
3590        LDA £0:STA temp:STA temp+1
3600        LDA £4:STA ctr
3610.Rptl   JSR Delayrd                           )
3620        LDA £&80:LDX £4:JSR OSBYTE            )
3630        STX templ:STY templ+1:LDX £6           )
3640.Div0   CLC:LSR templ+1:ROR templ:DEX         )
3641        BNE Div0                              )
3650        LDA templ:CLC:ADC temp:STA temp       ) delay loop to
3660        LDA templ+1:ADC temp+1:STA temp+1     ) allow pressure
3670        DEC ctr:BNE Rptl                      ) reading to stabilise
3680        LDA £2                                ) before recording
3690.Divl   CLC:LSR temp+1:ROR temp:LSR A         )
3691        BNE Divl                              )
3700        SEC:LDA temp:SBC channel:CMP £0       )
3701        BNE Trans                             )
3710        LDA average:STA ctr                   ) load rdgs to avge
3720        LDA £4:STA channel                    ) read on ADC ch. 4
3730        LDA £0:STA temp:STA temp+1
3740.Convert
3750        JSR Delayrd                           )
3760        LDA £&80:LDX channel:JSR OSBYTE       )
3770        STX templ:STY templ+1                 )
3780Ωreduce ADC value to 10 bits                  )
3790        LDX £6                                )
3800.Div    CLC:LSR templ+1:ROR templ:DEX         ) read ADC values
3801        BNE Div                               ) reduce to 10 bits
3810        LDA templ:CLC:ADC temp:STA temp       ) and average
3820        LDA templ+1:ADC temp+1:STA temp+1     )
3830        DEC ctr:BNE Convert                   )
3840        LDA average                           )
3850.Avge                                         )
3860        CLC                                   )
3870        LSR temp+1                            )
3880        ROR temp                              )
3890        LSR A:CMP £1:BNE Avge                 )
3900Ω
3910.Store LDA £&6F:LDX £&81:JSR OSBYTE           )
3920        LDY £0                                )
3930        LDA temp:STA (AREAD),Y                ) store data
3940        INY                                   ) in shadow RAM
3950        LDA temp+1:STA (AREAD),Y              )
3960        LDA £&6F:LDX £&C0:JSR OSBYTE          )
4020Ω
4030Ω print out value                             )
4040        LDA temp:STA Lobyte                   ) print data on screen
4050        LDA temp+1:STA Hibyte                 )
```

```
4060        JSR Print:JSR Fwdspce                   )
4070\
4080.Incptr                                         )
4090        CLC:LDA £2:ADC AREAD:STA AREAD          )
4100        LDA £0:ADC AREAD+1:STA AREAD+1          )
4110        LDX channel:CPX £3:BEQ Endrd            ) increment ptrs
4120        DEX:STX channel                         ) repeat for ADC
4130        LDA average:STA ctr                     ) channel 3
4140        LDA £0:STA temp:STA temp+1              )
4150        JMP Convert                             )
4160.Endrd RTS
4170\
4180\Delay loop between adc readings
4190.Delayrd                                        )
4200        LDA delayrd+1                           )
4210        STA ctrl+1                              )
4220.DR1    LDA delayrd                             )
4230        STA ctrl                                )
4240.DR2    LDY £10                                 )
4250.DR3    LDX £255                                )
4260.DR4    DEX:CPX £0:BNE DR4                      )
4270        DEY:CPY £0:BNE DR3                      )
4280        DEC ctrl                                )
4290        BNE DR2                                 )
4300        LDA £0                                  )
4310        CMP ctrl+1                              )
4320        BEQ Endlyrd                             )
4330        DEC ctrl+1                              )
4340        JMP DR1                                 ) delay subroutines
4350.Endlyrd                                        )
4360        RTS                                     )
4370\                                               )
4380\Delay loop between pulses                      )
4390.Delay                                          )
4400        LDA delay+1                             )
4410        STA ctrl+1                              )
4420.D1     LDA delay                               )
4430        STA ctrl                                )
4440        LDA £0                                  )
4450.D2     DEC ctrl                                )
4460        BNE D2                                  )
4470        CMP ctrl+1                              )
4480        BEQ endly                               )
4490        DEC ctrl+1                              )
4500        JMP D1                                  )
4510.endly RTS                                      )
4520.Inkey
4530        LDX £0:LDY £0:LDA £&81:JSR OSBYTE       )
4540        CPY £&1B:BEQ Escape                     )
4550        CPY £0:BNE Nokey                        ) escape pressed
4560        STX inkey                               ) subroutine
4570        RTS                                     )
4580.Escape                                         )
4590        LDA £&7E:JSR OSBYTE:LDA £&1B:RTS        )
4600.Nokey                                          )
4610        LDA £0:RTS                              )
4620\routine to output ang and vely to screen
4630.Locheck EQUB 0
4640.Hicheck EQUB 0
```

```
4650.Lobyte EQUB 0
4660.Hibyte EQUB 0
4670.TTHOU EQUW 10000
4680.THOU  EQUW 1000
4690.HUN  EQUW 100
4700.TEN   EQUW 10

4710.Print                                    DATA ON SCREEN ROUTINE

4720        LDY £0
4730        LDA TTHOU:STA Locheck
4740        LDA TTHOU+1:STA Hicheck
4750        JSR LOOP
4760        LDA THOU:STA Locheck
4770        LDA THOU+1:STA Hicheck
4780        JSR LOOP
4790        LDA HUN:STA Locheck
4800        LDA HUN+1:STA Hicheck
4810        JSR LOOP
4820        LDA TEN:STA Locheck
4830        LDA TEN+1:STA Hicheck
4840        JSR LOOP
4850        LDA £1:STA Locheck
4860        LDA £0:STA Hicheck
4870        JSR LOOP
4880        RTS
4890Ω
4900Ω
4910.LOOP  LDA Lobyte:STA ctrl
4920        LDA Hibyte:STA ctrl+1
4930.LOOP1
4940        LDA ctrl:SEC:SBC Locheck:STA ctrl
4950        LDA ctrl+1:SBC Hicheck:STA ctrl+1
4960        BMI NXT
4970        INY:JMP LOOP1
4980.NXT JSR PRNT
4990        LDA ctrl:CLC:ADC Locheck:STA Lobyte
5000        LDA ctrl+1:ADC Hicheck:STA Hibyte
5010        LDY £0
5020        RTS
5030Ω
5040Ω
5050.PRNT
5060        TYA:CLC:ADC £&30:JSR OSASCI:RTS
5070 .Tab
5080        LDA £&1F:JSR OSWRCH:LDA£7:JSR OSWRCH:LDA£22:JSR OSWRCH
5090        RTS
5100.Fwdspce
5110        LDY £13
5120.Fwdlp LDA £&09:JSR OSWRCH
5130        DEY:BNE Fwdlp
5140        RTS
5150Ω
5160]NEXT OPT%
5170*SAVE 3D.MC 1A00 2500
5180PRINT"C=&";²moves
```

PROGRAMME LISTING FOR - SURFBAS

```
 10REM********************************
 20REMPROG SURFBAS OCTOBER 1985 WRITTEN BY D.J. SEARLE
 30REM RUNS IN CONJUNCTION WITH LONGMC
 40REMPAGE MUST BE SET AT 1C00
 50REM HIMEM=&4000 AVAILABLE SPACE TO &5800: 6K OF MEMORY
 60PT=&4000
 70HIMEM=PT
 80 @%=131594
 90 PORTB = &FE60
100 DDRB = &FE62
110 ADPTR=&70
120 OSFIND=&FFCE
130 OSBYTE=&FFF4
140 DTASTR=PT+50
150 delay=PT
160 steps=PT+9
170 filename=PT+10
180 fchan=PT+20
190 eflag=PT+21
200REM***************************
210 AA$=""
220 AB$=""
230 AC$=""
240 AD$=""
250 BR$=""
260 S=0
270T=0
280 DISC=5
290 A0%=50
300REM**************************
310 *LOAD SURFMC 1A00
320 start=&1A00
330 pulse11=&1A37
340 pulse22=&1A61
350 on1=&1A13
360 on2=&1A25
370 off1=&1A1C
380 off2=&1A2E
390 blnkfile=&1AEB
400 openfile=&1AF8
410 closefile=&1B05
420 REM******************************
430MODE7
440PROCintro
450PROCoptions
460MODE4
470PROCprobeset
480PROCset
490IF AD$="S" THEN 510
500PROCparameter
510PROCrun
520IF AD$="S" THEN 470
530REM*************************
540SCROLL=0
550CLS
560SCROLL=SCROLL+150
```

```
570IF SCROLL=600 THEN CLS:SCROLL=0
580PRINT TAB(0,2)"                                    "
590PRINT TAB(0,0)"Data points to average?"
600PRINT TAB(0,1)"Default is 30"
610INPUT TAB(0,2);R
620IF R=0 THEN R=30
630 L=0
640 tot=0
650 N1=DTASTR
660 hiaddr=?ADPTR+256*(ADPTR?1)
670 readings=INT((hiaddr-DTASTR)/2)
680 FOR MM=0 TO 2*(R-1) STEP 2
690 tot=tot+(N1?MM+256*(N1?(MM+1)))/64
700 NEXT MM
710 Z1%=INT(tot*10/(A0%*R))
720 MOVE 0,Z1%*2+SCROLL
730 FOR N=N1 TO hiaddr-2*R STEP 2*R
740 tot=0
750 FOR M=0 TO 2*(R-1) STEP 2
760 tot=tot+(N?M+256*(N?(M+1)))/64
770 NEXT M
780 Z%=INT(tot*10/(A0%*R))
790 DRAW 600*L*R/readings,Z%*2+SCROLL
800 L=L+2
810 NEXT N
820PRINT TAB(0,2)"Averaged plot O.K.?"
830A$=INKEY$(0)
840IF A$=CHR$(&0D) AND AA$="N" THEN1060
850IF A$=CHR$(&0D)THEN880
860IF A$="N" THEN560
870GOTO830
880PRINT TAB(0,2)"Data being processed"
890L=0
900FOR N=N1 TO hiaddr-2*R STEP 2*R
910tot=0
920FOR M=0 TO 2*(R-1) STEP 2
930tot=tot+(N?M+256*(N?(M+1)))/64
940NEXT M
950Z%=INT(tot*10/(A0%*R))
960DTASTR?L=Z% MOD 256
970DTASTR?(L+1)=Z% DIV 256
980L=L+2
990NEXT N
1000 FOR I=L TO L+40 STEP 2
1010 DTASTR?I=999 MOD 256
1020 DTASTR?(I+1)=999 DIV 256
1030 NEXT I
1040 PROCfile2
1050 PRINT TAB(0,2)"Data  filed          "
1060 PRINT TAB(0,3)"Return to continue else Stop   "
1070 AC$=INKEY$(0)
1080 IF AC$=CHR$(&0D) THEN460
1090 IF AC$="S" THEN STOP
1100 GOTO1070
1110REM***************************
1120REM  subroutines for disk filing
1130REM***************************
1140 DEF PROCwrite
1150 L1=LEN(D$)
```

```
1160 FOR I=1 TO L1
1170 E=ASC(MID$(D$,I,1))
1180 BPUT£chan,E
1190 NEXT
1200 BPUT£chan,10
1210 BPUT£chan,10
1220 BPUT£chan,13
1230 ENDPROC
1240 REM****************************
1250 DEF PROCfile1
1260 PROCopenfile
1270 LET D$="DATE OF RUN   "+DATE$
1280 PROCwrite
1290 LET D$="DISCHARGE IN L/S   "+STR$(DISC)+"  GATE SETTING  "+STR$(GATE)
1300 PROCwrite
1310 D$="  X    Y  DIST  Q  LEVEL"
1320 PROCwrite
1330 PROCclosefile
1340 ENDPROC
1350REM*****************************
1360 DEF PROCfile2
1370DIST=1.25*R*SR/48
1380LAT0%=INT(LAT0%-DIST/2+0.5)
1390 PROCopenfile
1400 D$=STR$(LAT0%)+" "+STR$(LONG0%)+" "+MID$(STR$(DIST),1,4)+" "+STR$(LEVEL)
1410 PROCwrite
1420 FOR I=1 TO L+20 STEP 20
1430 FOR K=I TO 19+I STEP 2
1440 Z%=DTASTR?(K-1)+256*DTASTR?K
1450IF NOT(Z%=999) THEN1460 ELSE 1470
1460Z%=Z%-Z1%+LEVEL*10
1470 FOR J=1 TO LEN(STR$(Z%))
1480 Z=ASC(MID$(STR$(Z%),J,1))
1490 BPUT£chan,Z
1500 NEXT J
1510 BPUT£chan,32
1520 NEXT K
1530 BPUT£chan,10
1540 BPUT£chan,13
1550 NEXT I
1560 PROCclosefile
1570 ENDPROC
1580REM*******************************
1590DEF PROCnewfile
1600PRINT"Procedure to open new file"
1610INPUT"ENTER FILENAME  "N$
1620IF LEN(N$)>7  OR N$="" THEN 1610
1630$filename=N$
1640CALL blnkfile
1650chan=?fchan
1660fptr=PTR£chan
1670PRINT£chan,fptr
1680fptr=PTR£chan
1690PTR£chan=0
1700PRINT£chan,fptr
1710FOR X=1 TO 12000
1720BPUT£chan,255
1730NEXT
1740CALL closefile
```

```
2820GOTO2790
2830PRINT"       STPX      STPY      STPZ     MIN%(J)"
2840FORJ=1TON-1
2850PRINT STP%(1,J),STP%(2,J),STP%(3,J),MIN%(J):NEXT
2860PRINT
2870PRINT"          STEPPED POSITIONS"
2880PRINT"        X         Y         Z"
2890FORJ=1TON-1
2900PRINT TT%(1,J),TT%(2,J),TT%(3,J):NEXT
2910VDU6:VDU3
2920PRINT TAB(28)"Return to continue"
2930REPEAT:UNTIL GET=&0D
2940CLS
2950REM******************************
2960REM Section to input data to m/c programme
2970REM******************************
2980J=0
2990FORI=0TO2*(N-1)STEP2
3000J=J+1
3010STP%(1,J)=ABS(STP%(1,J))
3020STP%(2,J)=ABS(STP%(2,J))
3030STP%(3,J)=ABS(STP%(3,J))
3040stpx?I=STP%(1,J)MOD256                   )
3050stpx?(I+1)=STP%(1,J)DIV256               )
3060stpy?I=STP%(2,J)MOD256               ) store unit steps in
3070stpy?(I+1)=STP%(2,J)DIV256           ) X,Y,Z directions
3080stpz?I=STP%(3,J)MOD256                   )
3090stpz?(I+1)=STP%(3,J)DIV256               )
3100minj?I=MIN%(J)MOD256                 ) store total no. unit
3110minj?(I+1)=MIN%(J)DIV256             ) cycles between each
3120NEXTI                                ) traverse
3130REM******************************
3140PRINT TAB(29,2)"Alter stepping rate?"
3150K=GET:IF K=89 THEN 3160 ELSE IF K=78 THEN 3230:GOTO3150
3160INPUT TAB(22,3)"DELAY (1-20) - DEFAULT=10)";DLY
3170IFDLY=0 THEN DLY=10
3180DLY=DLY+90
3190?delay=DLY*5 MOD 256                ) set delay
3200delay?1=DLY*5 DIV 256               )
3210GOTO3250
3220REM******************************
3230?delay=244
3240delay?1=1
3250?moves=N
3260?delayrd=L
3270delayrd?1=H
3280?average=AVGE
3290CHAIN"3D.RUN"                      ) chain next programme
3300REM******************************
3310DEF PROCcontinue
3320PRINT TAB(25,30)"Return to Continue"
3330K=GET:IF K=&0D THEN3340:GOTO3330
3340CLS
3350ENDPROC
```

```
1750ENDPROC
1760REM*******************************
1770DEF PROCopenfile
1780 PRINT
1790INPUT TAB(0,3)"ENTER FILENAME  "N$
1800IF LEN(N$)>7 OR N$="" THEN 1790
1810$filename=N$
1820CALL openfile
1830chan=?fchan
1840IF chan=0 THEN PROCclosefile
1850PTR£chan=0
1860INPUT£chan,fptr
1870PTR£chan=fptr
1880ENDPROC
1890REM*******************************
1900DEF PROCclosefile
1910fptr=PTR£chan
1920PTR£chan=0
1930PRINT£chan,fptr
1940CALL closefile
1950ENDPROC
1960REM*******************************
1970 DEF PROCparameter
1980T=T+1
1990CLS
2000IF NOT(BR$="") THEN2140
2010IF NOT(AA$="") THEN2180
2020 PRINT TAB(0,0)"Do you wish to store data on disk today?,y/n"
2030 AA$=INKEY$(0)
2040 IF AA$="Y" THEN 2070
2050 IF AA$="N" THEN 2180
2060 GOTO2030
2070 PRINT TAB(0,2)"Do you need to open a new file,y/n"
2080 AB$=INKEY$(0)
2090 IF AB$="Y" THEN 2120
2100 IF AB$="N" THEN 2130
2110 GOTO2080
2120 PROCnewfile
2130 INPUT TAB(0,5)"DATE e.g. 3/1/85        ";DATE$
2140 INPUT TAB(0,7)"CALIBRATION COEFFICIENT (UNITS/MM) ";A0%
2150IF NOT(BR$="")THEN 2180
2160 INPUT TAB(0,9)"DISCHARGE (L/S)  ";DISC
2170 INPUT TAB(0,11)"GATE SETTING  ";GATE
2180 INPUT TAB(0,13)"X-COORD Y-COORD AT START ";LAT0%,LONGO%
2190 INPUT TAB(0,15)"SURFACE LEVEL AT START ";LEVEL
2200 PRINT TAB(0,16)"Correct values?"
2210A$=INKEY$(0)
2220IF A$=CHR$(&0D) THEN2260
2230IF A$="N" AND AA$="N" THEN CLS:GOTO2180
2240IF A$="N" AND AA$="Y" THEN CLS:GOTO2130
2250GOTO2210
2260IF AA$="N" OR T>1 OR NOT (BR$="") THEN2290
2270CLS
2280PROCfile1
2290BR$=""
2300ENDPROC
2310REM*****************************
2320DEF PROCprobeset
2330CALL start
```

```
2340?steps=255
2350?delay=150
2360delay?1=01
2370CLS
2380PRINT TAB(0,0)"Horizontal-X or Vertical-Z stepper?"
2390PRINT TAB(9,2)"Return to Miss"
2400REPEAT
2410L=GET
2420UNTIL L=88 OR L=90 OR L=&0D
2430IF L=90 THEN2510
2440IF L=&0D THEN2690
2450PRINT TAB(0,2)"For motor direction      "'"Enter L-left or R-right"
2460REPEAT
2470K=GET
2480IF K=82 THEN CALL off1:GOTO2570
2490IF K=76 THEN CALL on1:GOTO2570
2500UNTIL K=76 OR K=82
2510PRINT TAB(0,2)"For motor direction     "'"Enter U-up or D-down"
2520REPEAT
2530K=GET
2540 IF K=68 THEN CALL off2:GOTO2570
2550IF K=85 THEN CALL on2:GOTO2570
2560UNTIL K=68 OR K=85
2570PRINT TAB(0,4)"Motor "CHR$(L)" called in ";CHR$(K);" Direction."
2580PRINT TAB(0,5)"Start?"
2590KK=GET:IF K=&0D THEN 2600:GOTO2590
2600PRINT TAB(0,8)"RESETTING PROBE TO START POSITION"
2610PRINT TAB(0,6)"To stop press space bar"
2620IF L=88 THEN CALL pulse11
2630IF L=90 THEN CALL pulse22
2640PRINT TAB(0,8)"Restart motors? Otherwise Quit        "
2650REPEAT V$=INKEY$(0)
2660IF V$=CHR$(&0D) THEN 2370
2670IF V$="Q" THEN 2690
2680UNTIL FALSE
2690 ENDPROC
2700 REM*****************************
2710DEF PROCrun
2720CALL start
2730CLS
2740PRINT TAB(0,0)"For motor direction"'"Enter L-left or R-right"
2750REPEAT
2760K=GET
2770IF K=82 THEN CALL off1:GOTO2800
2780IF K=76 THEN CALL on1:GOTO2800
2790UNTIL K=76 OR K=82
2800 PRINT TAB(0,2)"Motor X called in ";CHR$(K);" Direction."
2810PRINT TAB(0,3)"Start?"
2820K=GET:IF K=&0D THEN2830:GOTO2820
2830PRINT TAB(0,6)"RUN STARTED TOWARDS ";CHR$(K);" EDGE"
2840PRINT TAB(0,3)"To stop press space bar"
2850CALL pulse11
2860PRINT TAB(0,6)"Store data? To scrap and re-run 'S'              "
2870K=GET:IF K=&0D THEN 2880:GOTO2870
2880ENDPROC
2890 REM*****************************
2900 DEF PROCset
2910CLS
2920PRINT TAB(0,0)"SETTING UP INITIAL PARAMETERS FOR RUN"
```

```
2930 PRINT TAB(0,2)"Steps between unaveraged readings"
2940 PRINT TAB(0;3)"Default is 12"
2950INPUT TAB(0,4);SR
2960IF SR=0 THEN SR=12
2970?steps=SR
2980PRINT TAB(0,6)"Stepping rate? (1-10)"
2990PRINT TAB(0,7)"Default is 5"
3000INPUT TAB(0,8);DL
3010DL=DL*200
3020IF DL=0 THEN DL=1025
3030?delay=DL MOD 256
3040delay?1=DL DIV 256
3050 ENDPROC
3060REM******************************
3070DEF PROCintro
3080PRINT TAB(10,10);CHR$(141)"Programme Surfbas"
3090PRINT TAB(10,11);CHR$(141)"Programme Surfbas"
3100 PRINT TAB(3,12)"AUTOMATIC SURFACE  DATA COLLECTION"
3110PRINT TAB(7,14)"OCTOBER 1985 D.J. SEARLE"
3120PRINT TAB(10,16)"Return to continue"
3130TIME=0
3140REPEAT
3150A$=INKEY$(0)
3160IF A$=CHR$(&0D) THEN3180
3170UNTIL TIME=500
3180CLS
3190PRINT TAB(0,4)"Programme to run an automatic"'"data collection facility."
3200 PRINT TAB(10,16)"Return to continue"
3210TIME=0
3220REPEAT
3230A$=INKEY$(0)
3240 IF A$=CHR$(&0D) THEN3260
3250UNTIL TIME=1500
3260ENDPROC
3270DEF PROCoptions
3280CLS
3290PRINT TAB(1,2);CHR$(141)"    Choose options to continue"
3300PRINT TAB(1,3);CHR$(141)"    Choose options to continue"
3310PRINT TAB(5,8)"Begin new set of runs    -  1"
3320PRINT TAB(5,11)"Continue runs from break :"
3330PRINT TAB(5,12)"Collecting data on disk  -  2"
3340PRINT TAB(5,13)"VDU runs only            -  3"
3350PRINT TAB(5,16)"Terminate programme      -  4"
3360K=GET
3370 IF K=49 THEN 3420
3380 IF K=50 THEN AA$="Y": BR$="B":GOTO3420
3390IF K=51 THEN AA$="N" AND BR$="B":GOTO3420
3400IF K=52 THEN STOP
3410GOTO3360
3420CLOSE £0
3430ENDPROC
```

PROGRAMME LISTING - ADVAL

```
10REMPROGRAMME TO READ ADC CHANNELS
20REMADAPTED FOR VELOCITY AND ANG
30REMREADINGS
40REM*****************************
50REM**********ADVAL*************
60REM***DJ SEARLE**UOB***********
70REM*****OCTOBER 1985***********
80MODE7
90PROCintro
100CLS
110PRINT TAB(0,0)"Calibrate Angular Displacement Inst."
120PRINT TAB(0,2)"ANGO%=ADC readout at zero displacement"
130PRINT TAB(0,3)"CAL%=rotation in degrees/unit"
140PRINT TAB(0,5)"ENTER TRANSDUCER RATING MBAR"
150INPUT TAB(30,5);RAT%
160PRINT TAB(0,6)"Set probe to zero position"
170PRINT TAB(0,7)"Return to enter value currently read"
180REPEAT:A$=INKEY$(0):ANGO%=ADVAL(3)/64:PRINT TAB(5,9)"ANGO%=  ";ANGO%:UNTIL A$=
                                                                  CHR$(&0D)
190PRINT TAB(0,6)"Set probe to +90 degrees   "
200PRINT TAB(0,7)"Return to enter value currently read"
210REPEAT:A$=INKEY$(0):MAX%=ADVAL(3)/64:PRINT TAB(5,10)"MAX%=  ";MAX%:UNTIL A$=CH
                                                                    $(&0D)
220PRINT TAB(0,6)"Set probe to -90 degrees"
230PRINT TAB(0,7)"Return to enter value currently read"
240REPEAT:A$=INKEY$(0):MIN%=ADVAL(3)/64:PRINT TAB(5,11)"MIN%=  ";MIN%:UNTIL A$=CH
250MODE0                                                              $(&0D)
260PRINT TAB(6,0)"  CH1       CH2       ANG       VELY"
270PRINT TAB(0,3)"ANGO%= ";ANGO%
280PRINT TAB(0,4)"MAX%-MIN%= ";MAX%-MIN%
290PRINT TAB(0,7)"ANGULAR DISP=          DEGREES "
300PRINT TAB(0,6)"VELOCITY=         MM/S"
310IF RAT%=0 THEN RAT%=2
320CAL%=MAX%-MIN%
330IF CAL%<10 THEN CAL%=600
340PRINT TAB(11,8)"Return to Stop"
350REPEAT
360VDU24,0;0;1279;500;
370MOVE 0,0
380DRAW 1200,0
390DRAW1200,500
400DRAW 0,500
410DRAW 0,0
420TIME=0
430PRINT TAB(0,30) "0          10          20          seconds          40
440REPEAT
450PRINT TAB(0,1)INT(ADVAL(1)/64),INT(ADVAL(2)/64),INT(ADVAL(3)/64),INT(ADVAL(4)
460VELY=226*SQR(ADVAL(4)/64*(5/1118))                                 /64
470VELY%=VELY
480PRINT TAB(13,6)"    "
485*FX19
490PRINT TAB(13,6);VELY%
500ANG=(ADVAL(3)/64-ANGO%)*(180/ABS(CAL%))
510ANG%=ANG*10
520ANG%=ANG%/10
530PRINT TAB(17,7)"    "
540PRINT TAB(17,7);ANG%
550PLOT 5,TIME/5,VELY%
```

```
551SOUND1,-5,VELY%/3,5
560UNTIL TIME>6000
570MOVE0,0
580CLG
590A$=INKEY$(0)
600UNTIL A$=CHR$(&0D)
610STOP
620END
630REM******************************
640DEF PROCintro
650PRINT TAB(10,10)"PROGRAMME   ADVAL"
660PRINT TAB(5,12)"ANALOGUE/DIGITAL READ PROGRAMME"
670PRINT TAB(7,14)"OCTOBER 1985 D.J. SEARLE"
680PRINT TAB(10,16)"Return to continue"
690TIME=0
700REPEAT
710A$=INKEY$(0)
720IF A$=CHR$(&0D) THEN740
730UNTIL TIME=500
740CLS
750 PRINT TAB(0,4)"Programme to read ADC convertors"''"Adapted to read angular di
760PRINT TAB(0,11)"Setup apparatus-you are ready to start"   placement Transducer
770PRINT TAB(10,16)"Return to continue"
780TIME=0
790REPEAT
800A$=INKEY$(0):IF A$=CHR$(&0D) THEN820
810UNTIL TIME=500
820ENDPROC
```

PROGRAMME LISTING - CALIB

```
10REM******************************
20REMCALIBRATION PROGRAMME FOR DEPTH PROBE
30REM**********CALIB*************
40REM******DJSEARLE*OACTOBER1985**
50 PT=&5000
60 OSBYTE=&FFF4
70 MODE4
80 HIMEM=PT-1
90 DTASTR=PT+256
100 ctr=PT+1
110 cntr=PT+3
120 steps=PT+5
130 cntr2=PT+6
140 PORTB = &FE60
150 DDRB = &FE62
160 ADPTR=&70
170 DIM Z(1000)
180 DIM CODE% 520
190 FOR I%=0 TO 2 STEP 2
200 P%=CODE%
210 [OPT I%
220 .START     LDA £&FF
230            STA DDRB
240            LDA £DTASTR MOD 256
250            STA ADPTR
260            LDA £DTASTR DIV 256
270            STA ADPTR+1
280            LDA £&01
290            STA cntr
300            RTS
310Ω routines,off/on-direction of
320Ω motor drives
330Ω
340.on2        LDA £&04
350            ORA PORTB
360            STA PORTB
370            RTS
380.off2       LDA £&FB
390            AND PORTB
400            STA PORTB
410            RTS
420Ω******************************
430Ω pulsing motor two
440.pulse22
450            LDA £&40
460            ORA PORTB
470            STA PORTB
480            JSR delaysub
490            LDA £&BF
500            AND PORTB
510            STA PORTB
520            JSR delaysub
530            JSR readadc
540            LDA £&00
550              DEC cntr2
560              BNE pulse22
```

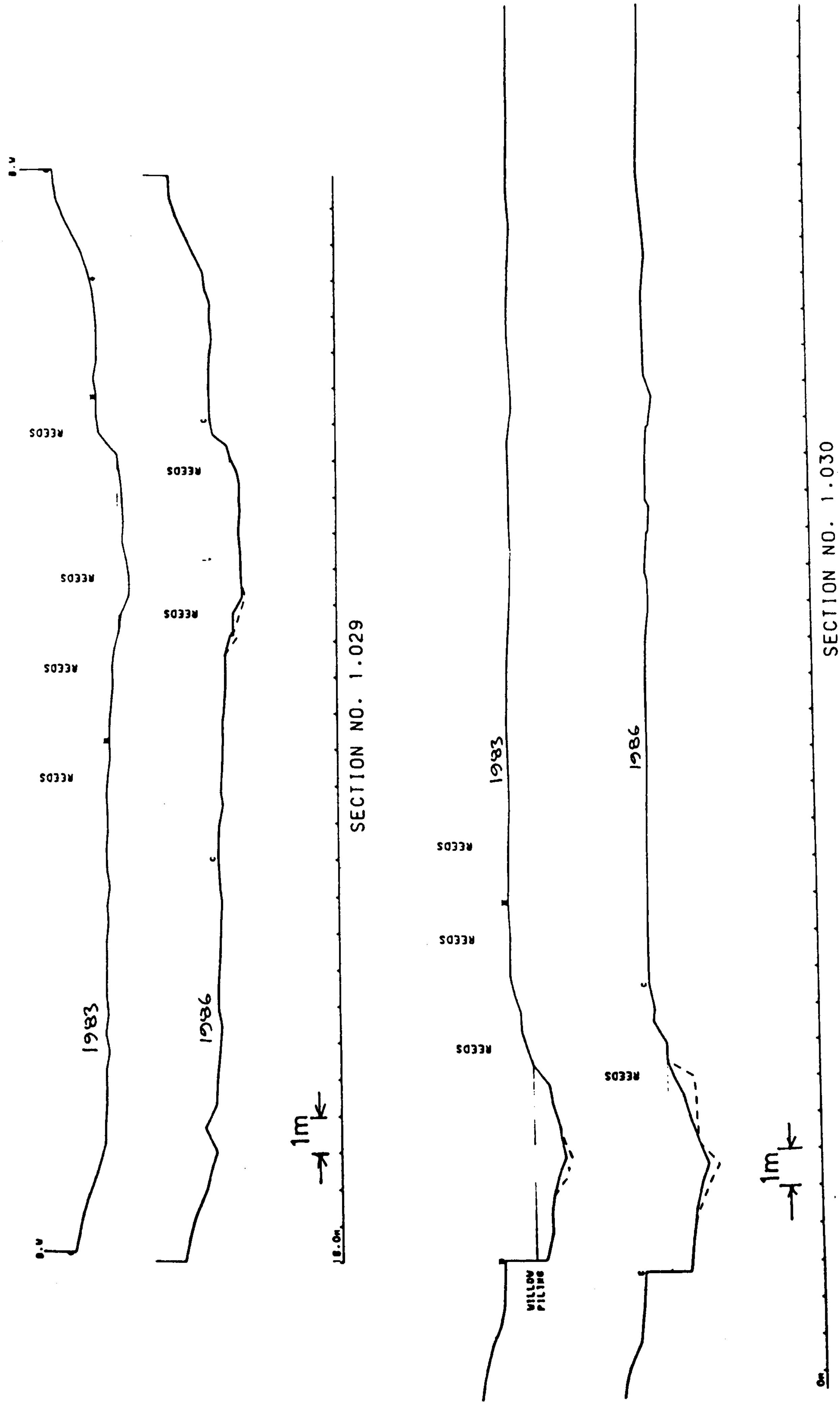
```
570             CMP cntr2+1
580             BEQ endpls22
590              DEC cntr2+1
600            JMP pulse22
610.endpls22  RTS
620Ω*****************************
630Ω delay routine for pulse
640.delaysub
650            LDA £&05
660            STA ctr
670            LDA £&03
680            STA ctr+1
690            LDA £00
700.loop
710            DEC ctr
720            BNE loop
730            CMP ctr+1
740            BEQ enddly
750            DEC ctr+1
760            JMP loop
770.enddly     RTS
780Ωsub to read ad convertor
790.readadc    DEC cntr
800            BNE endread
810            LDA steps
820            STA cntr
830            LDA £&80
840            LDX £&02
850            JSR OSBYTE
860            TYA
870            LDY £&01
880            STA (ADPTR),Y
890            DEY
900            TXA
910            STA (ADPTR),Y
920.incptr     CLC
930            LDA £&02
940            ADC ADPTR
950            STA ADPTR
960            LDA £&00
970            ADC ADPTR+1
980            STA ADPTR+1
990.endread    RTS
1000]NEXT I%
1010PROCintro
1020CLS
1030PRINT TAB(0,4)"ADJUST SENSITIVITY OF PROBE"
1040PRINT TAB(0,6)"RAISE PROBE UNTIL JUST IMMERSED"
1050PROCspace
1060PRINT TAB(0,8)"ADJUST WAVE MONITOR CONTROLS"
1070FOR I=1 TO 10000
1080PRINT TAB(25,11)"        "
1090PRINT TAB(7,11)"MINIMUM VALUE ";ADVAL(2)/64
1100PRINT TAB(0,13)"Return to continue"
1110A$=INKEY$(50)
1120IF A$=CHR$(&0D) THEN 1150
1130NEXT
1140GOTO1070
1150PRINT TAB(0,13)"                   "
```

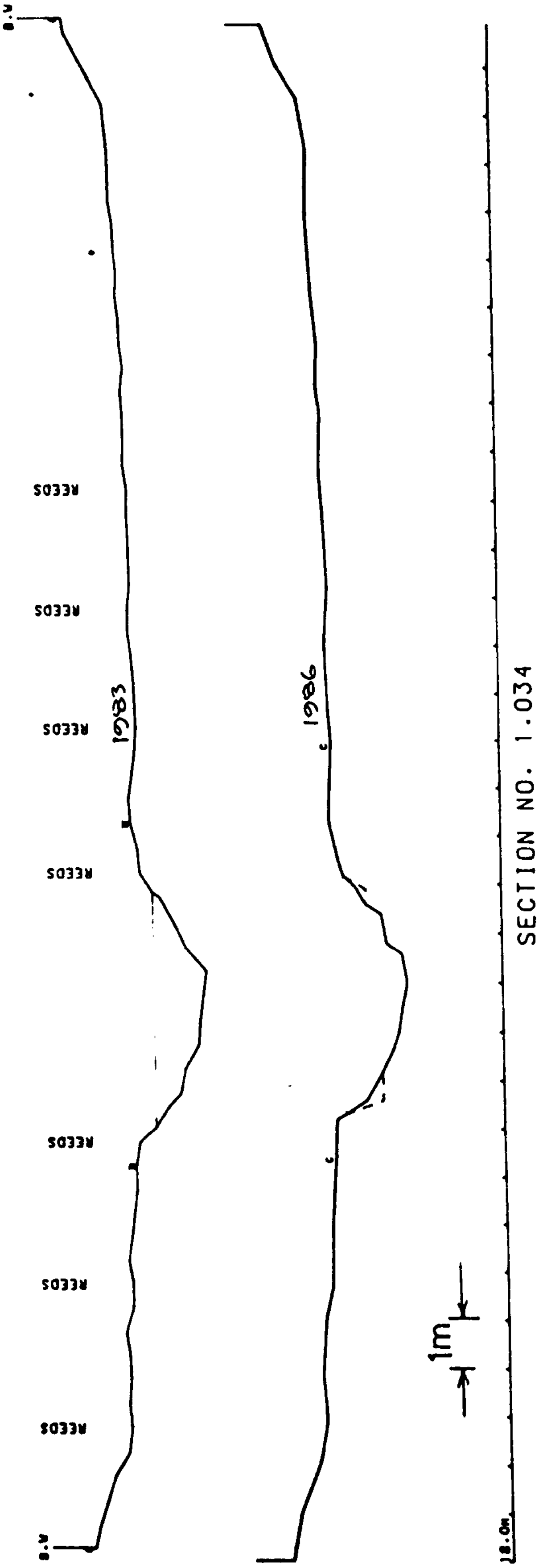
```
1160PRINT TAB(0,14)"IMMERSE PROBES TO MAXIMUM DEPTH"
1170FOR I=1 TO 10000
1180PRINT TAB(25,16)"      "
1190PRINT TAB(7,16)"MAXIMUM VALUE ";ADVAL(2)/64
1200PRINT TAB(0,18)"Return to contine"
1210A$=INKEY$(50):IF A$=CHR$(&0D) THEN 1240
1220NEXT
1230GOTO1170
1240PRINT TAB(0,18)"                    "
1250PRINT TAB(0,20)"Return to continue calibration"'"Else press space bar"
1260A$=INKEY$(0)
1270IF A$=" " THEN 1020 ELSE IF A$=CHR$(&0D) THEN 1290
1280GOTO1260
1290PRINT
1300 CLS
1310CALL START
1320MODE4
1330PRINT TAB(0,0)"Enter starting parameters"
1340PRINT TAB(0,2)"Up or Down?"
1350K=GET
1360IF K=68 THEN CALL off2:GOTO1390
1370IF K=85 THEN CALL on2 :GOTO1390
1380GOTO1350
1390INPUT TAB(0,4)"TRAVERSE IN MM   ";SC
1400INPUT TAB(0,5)"READINGS PER MM ";SR
1410PRINT TAB(0,6)"Entries correct?"
1420A$=INKEY$(0)
1430IF A$="N" THEN CLS:GOTO1330
1440IF A$=CHR$(&0D) THEN1460
1450GOTO1420
1460SC=INT(SC*48/1.25)
1470SR=INT(48/(1.25*SR))
1480PRINT TAB(0,8)"Total steps= ";SC;"and steps/rdg= ";SR
1490?cntr2=SC MOD 256
1500cntr2?1=SC DIV 256
1510?steps=SR
1520IF SC MOD 256=0 THEN ?cntr2=1
1530PRINT TAB(0,9)"Return to start else Quit"
1540 A$=INKEY$(0)
1550IF A$=CHR$(&0D) THEN 1580
1560IF A$="Q" THEN 2030
1570 GOTO1540
1580CLS
1590PRINT TAB(14,10);"RUN STARTED"
1600CALL pulse22
1610CLS
1620hiaddr =?ADPTR+256*ADPTR?1
1630 readings=(hiaddr-DTASTR)
1640MOVE 0,0
1650DRAW 1200,0
1660DRAW 1200,511
1670DRAW 0,511
1680DRAW 0,0
1690 L=1
1700 Z%=INT((DTASTR?0+256*DTASTR?(1))/64)
1710 MOVE 2400*L/readings,Z%/2
1720 FOR I=2 TO readings-2 STEP 2
1730 L=L+1
1740 Z%=INT((DTASTR?I+256*DTASTR?(I+1))/64)
```

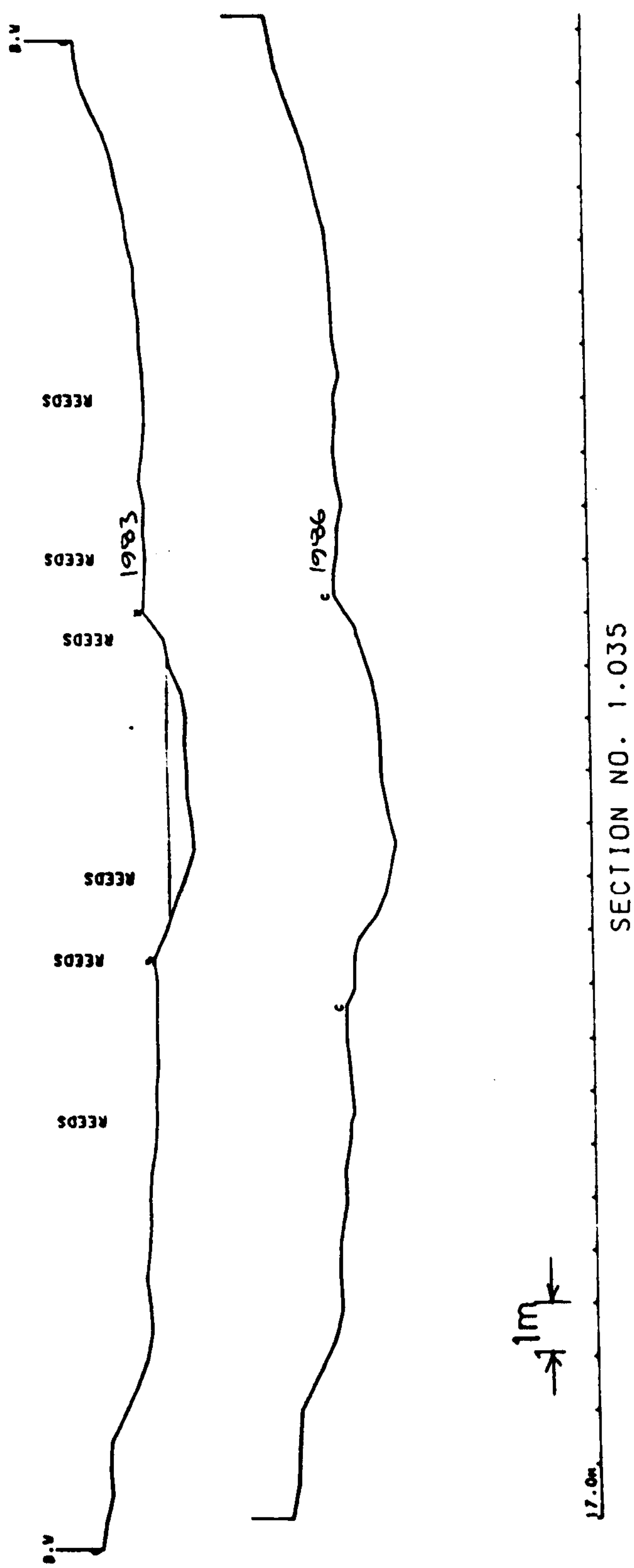
```
1750 DRAW 2400*L/readings,Z%/2
1760 DIST=(1.25/48)*SR
1770 Z(L)=Z%
1780 NEXT
1790 A1=0
1800 A2=0
1810 FOR J=1 TO L
1820 IF Z(J)>1000 OR Z(J)<24 THEN 1830 ELSE 1840
1830 NEXT J
1840 IF Z(J)>500 THEN A2=J+1 ELSE A1=J+1
1850 FOR K=J+1 TO L
1860 IF Z(K)>1010 OR Z(K)<10 THEN 1880 ELSE 1870
1870 NEXT K
1880 IF A2=(J+1) THEN A1=K ELSE A2=K
1890
1900 IF A1=(J+1) THEN X=1 ELSE X=-1
1910 N=0
1920 M%=0
1930PRINT TAB(32,0)"INT.VALS"
1940 FOR I=2 TO ABS(A2-A1)/20-1 STEP 1
1950 N=N+1
1960 TEMP=(Z(A1+20*I*X)-Z(A1+10*I*X))/(DIST*10*I)
1970 TEMP%=TEMP
1980 PRINT TAB(35,I+1);TEMP%
1990 A$=INKEY$(10)
2000 M%=INT(M%+TEMP+0.5)
2010 NEXT I
2020 M%=INT(M%/N+0.5)
2030 PRINT TAB(0,0)"CALIB. IS ";M%" UNITS/MM"
2040PRINT TAB(0,2)"RERUN?"
2050K=GET
2060IF K=89 THEN CLS:GOTO1300
2070IF K=78 THEN PRINT TAB(8,2)"CALIBRATION FINISHED":STOP
2080GOTO2050
2090REM****************************************
2100DEF PROCspace
2110PRINT TAB(0,0)"PRESS SPACE BAR TO CONTINUE"
2120REPEAT
2130K=GET
2140UNTIL K=&20
2150PRINT TAB(0,0)"                                 "
2160ENDPROC
2170REM******************************
2180DEF PROCintro
2190PRINT TAB(10,10)"PROGRAMME   CALIB"
2200PRINT TAB(5,12)"AUTOMATIC PROBE CALIBRATION"
2210PRINT TAB(7,14)"OCTOBER 1985 D.J. SEARLE"
2220PRINT TAB(10,16)"Return to continue"
2230TIME=0
2240REPEAT
2250A$=INKEY$(0)
2260IF A$=CHR$(&0D) THEN2280
2270UNTIL TIME=500
2280CLS
2290PRINT TAB(0,4)"Programme to calibrate depth probe used in measuring water
2300PRINT TAB(10,16)"Return to continue"                       surface"
2310TIME=0
2320REPEAT
2330A$=INKEY$(0)
```

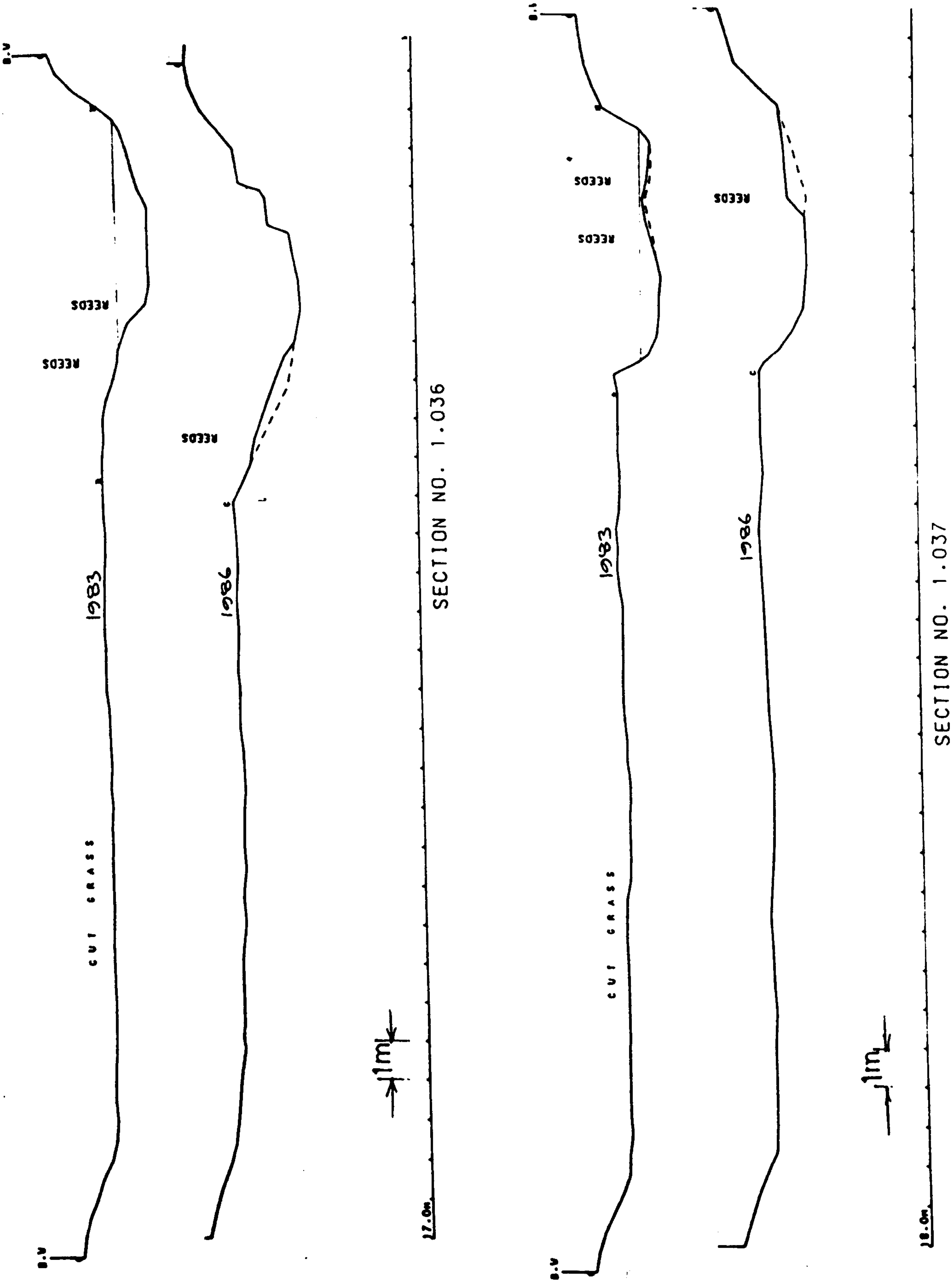
```
2340IF A$=CHR$(&0D) THEN2360
2350UNTIL TIME=500
2360ENDPROC
```

APPENDIX A.5


SECTION NO. 1.029
1983
1986
REEDS
1m
SECTION NO. 1.030
1983
1986
REEDS
WILLOW PILING
1m


SECTION NO. 1.034
1983
1986
REEDS
1m
18.0m


SECTION NO. 1.035
1983
1986
REEDS
1m
17.0m


SECTION NO. 1.036
SECTION NO. 1.037
1983
1986
REEDS
CUT GRASS
1m
17.0m
18.0m

Recorder No. 1 - Section 1.039
1984/1985

LEVEL (M)	DISCHARGE (M /S)	CROSS-SECTION AREA (M)	WETTED PERIMETER (M)
21.50	0.0	1.5	6.0
21.60	0.5	2.1	6.2
21.70	0.8	2.7	6.4
21.80	1.0	3.6	15.3
21.90	1.5	5.8	25.3
22.00	2.0	8.4	27.3
22.10	2.8	11.0	28.0

Recorder No. 1 - Section 1.039
1985/1986

21.50	0.0	1.5	6.0
21.60	0.8	2.1	6.2
21.70	1.3	2.7	6.4
21.80	1.5	3.6	15.3
21.90	2.5	5.8	25.3
22.00	3.3	8.4	27.3
22.10	4.3	11.0	28.0
22.20	7.0	13.8	28.6
22.30	8.5	16.6	28.8

Recorder No. 2 - Section 1.028
1984/1985

LEVEL (M)	DISCHARGE (M /S)	CROSS SECTION AREA (M)	WETTED PERIMETER (M)
21.00	0.0	1.7	6.0
21.10	0.5	2.5	8.2
21.20	1.3	3.4	9.6
21.30	2.5	4.2	35.8
21.40	3.8	6.4	44.3
21.50	5.5	9.2	48.3
21.60	7.3	12.1	48.5
21.70	8.8	15.0	49.6
21.80	10.5	17.9	49.8
21.90	12.2	20.9	50.3
22.00	14.5	23.9	50.6
22.10	16.0	27.0	51.7
22.20	17.5	30.0	52.7

Recorder No. 2 - Section 1.028
1985/1986

21.00	0.0	1.7	6.0
21.10	0.5	2.5	8.2
21.20	1.3	3.4	9.6
21.30	2.5	4.2	35.8
21.40	3.8	6.4	44.3
21.50	6.3	9.2	48.3
21.60	8.5	12.1	48.5
21.70	11.3	15.0	49.6
21.80	14.0	17.9	49.8
21.90	16.5	20.9	50.3
22.00	19.0	23.9	50.6
22.10	22.5	27.0	51.7
22.20	25.8	30.0	52.7
22.30	29.0	33.2	53.7

Recorder No. 3 - Section 1.010
1984/1985

LEVEL (M)	DISCHARGE (M /S)	CROSS-SECTION AREA (M)	WETTED PERIMETER (M)
19.70	0.0	1.2	6.4
19.80	0.5	1.8	8.7
19.90	1.3	2.8	10.2
20.00	1.5	4.1	15.7
20.10	3.0	5.9	19.2
20.20	4.0	7.8	19.8
20.30	5.8	11.8	20.3
20.40	7.0	13.9	20.8
20.50	8.5	16.1	22.3
20.60	10.0	18.4	22.9
20.70	11.5	20.7	23.1
20.80	13.3	23.1	24.0
20.90	15.3	25.6	24.5

Recorder No. 3 - Section 1.010
1985/1986

19.70	0.0	1.2	6.4
19.80	0.5	1.8	8.7
19.90	1.3	2.8	10.2
20.00	1.5	4.1	15.7
20.10	3.0	5.9	19.2
20.20	4.0	7.8	19.8
20.30	5.8	11.8	20.3
20.40	7.0	13.9	20.8
20.50	8.5	16.1	22.3
20.60	10.0	18.4	22.9
20.70	11.5	20.7	23.1

Between Sections 1.030 and 1.031 Looking Upstream

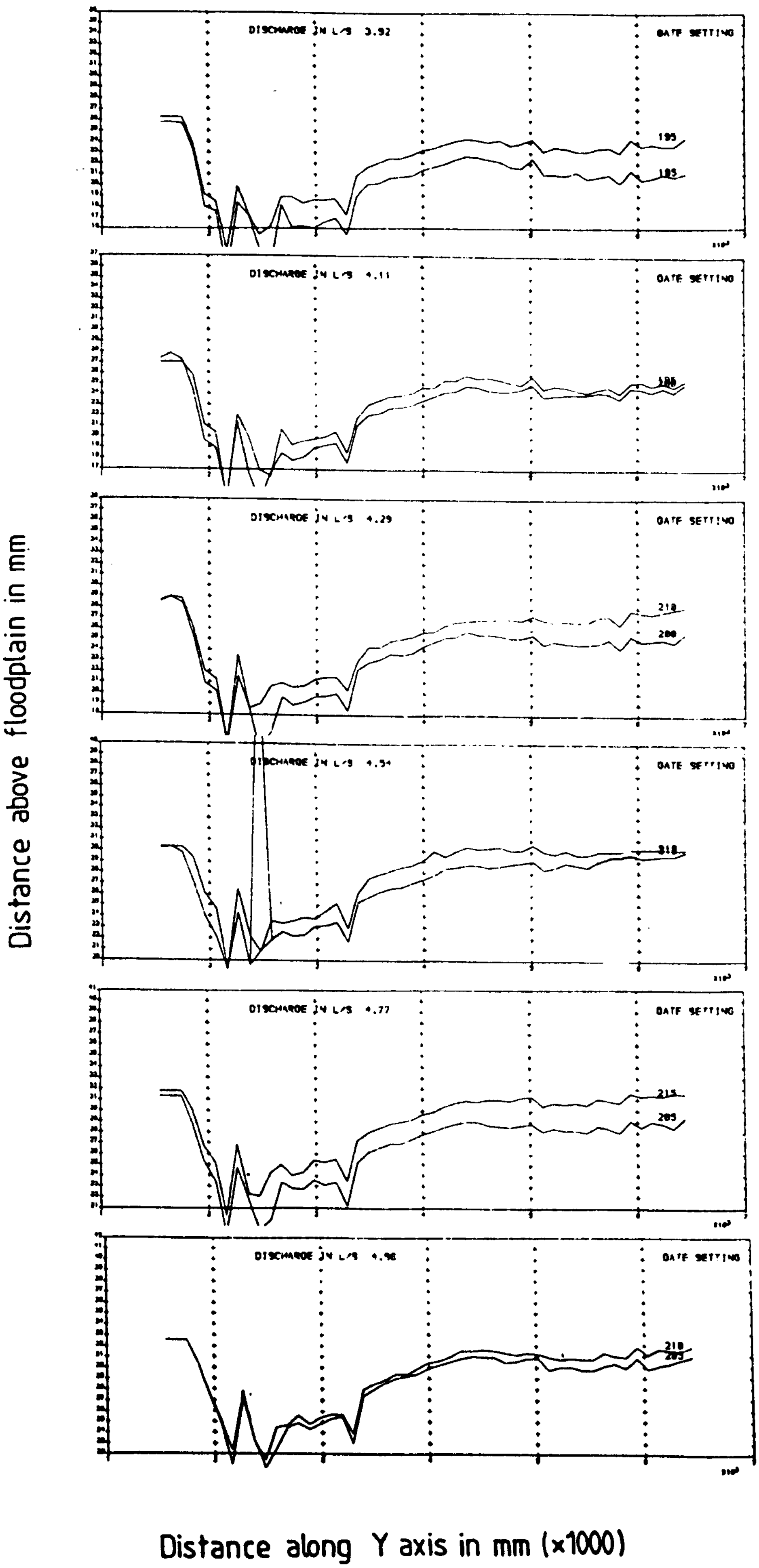
At Section 1.029 Looking Upstream

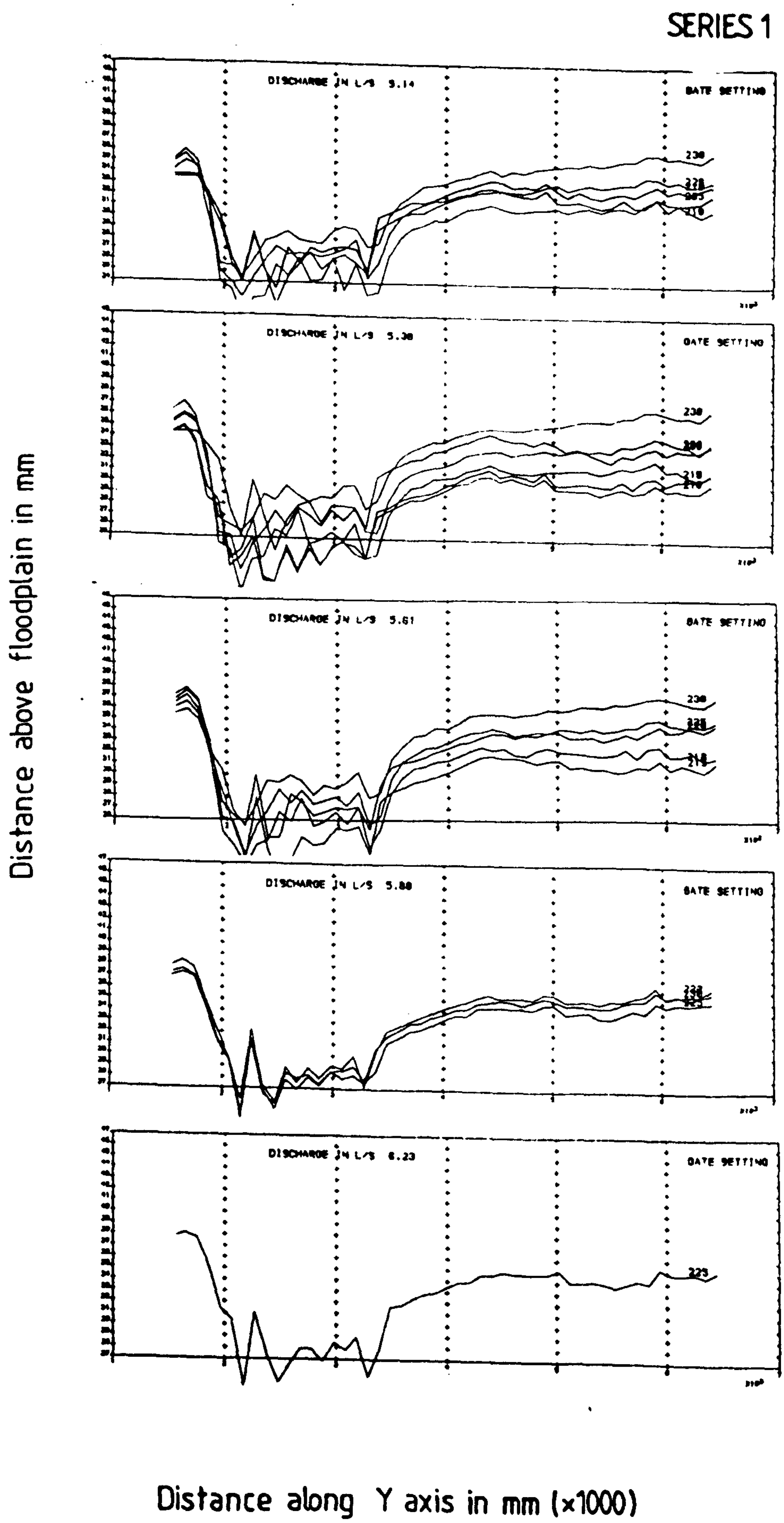
At Section 1.036 Looking Downstream

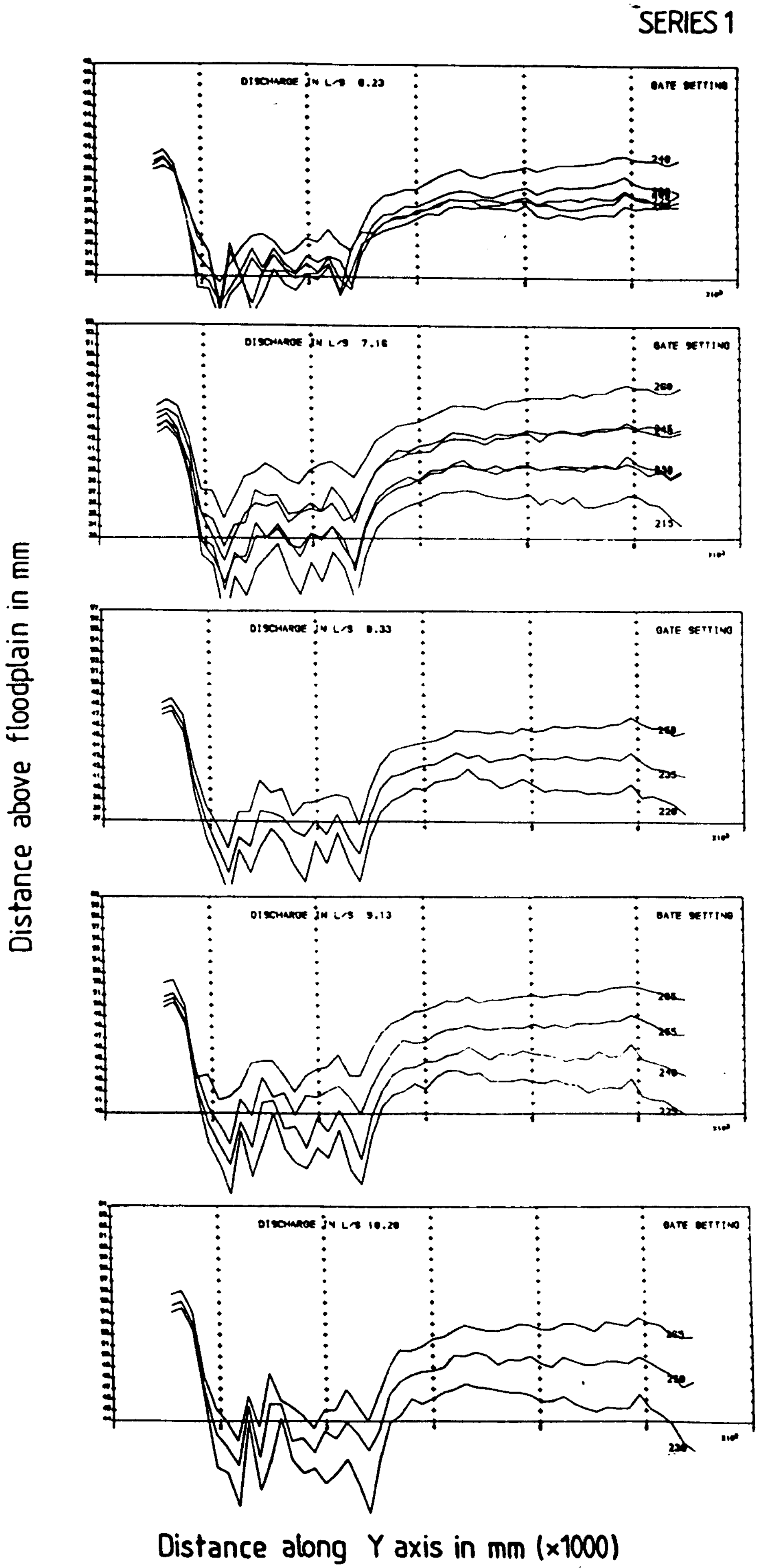
Between Section 1.034 and 1.035 Looking Downstream

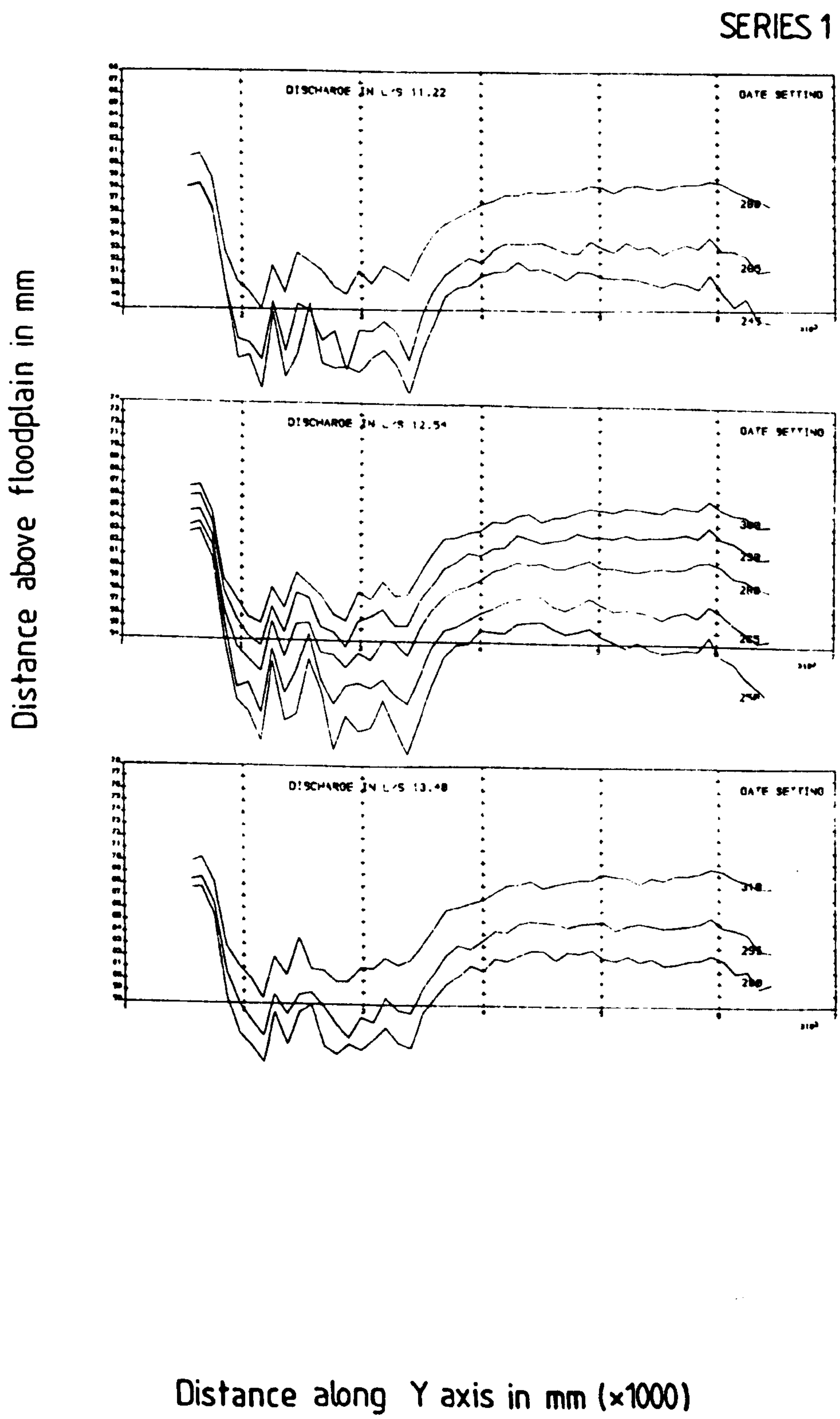
APPENDIX A.6

SERIES 1

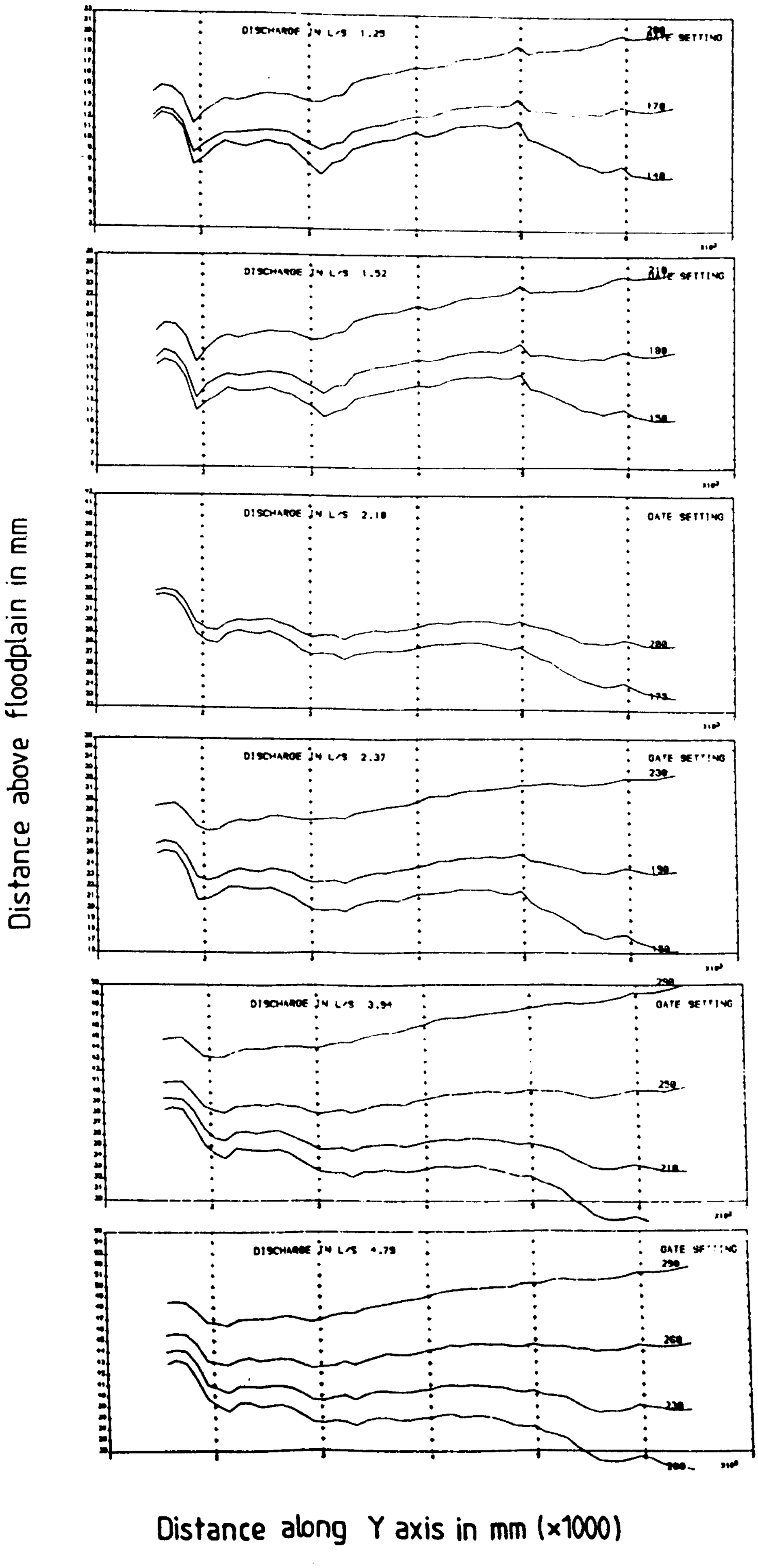

Distance above floodplain in mm
DISCHARGE IN L/S 3.92
GATE SETTING
195
185
DISCHARGE IN L/S 4.11
GATE SETTING
DISCHARGE IN L/S 4.29
GATE SETTING
210
200
DISCHARGE IN L/S 4.54
GATE SETTING
DISCHARGE IN L/S 4.77
GATE SETTING
215
205
DISCHARGE IN L/S 4.98
GATE SETTING
210
Distance along Y axis in mm (x1000)


SERIES 1
DISCHARGE IN L/S 5.14
GATE SETTING
230
DISCHARGE IN L/S 5.30
GATE SETTING
230
DISCHARGE IN L/S 5.61
GATE SETTING
230
DISCHARGE IN L/S 5.80
GATE SETTING
DISCHARGE IN L/S 6.23
GATE SETTING
225
Distance above floodplain in mm
Distance along Y axis in mm (x1000)

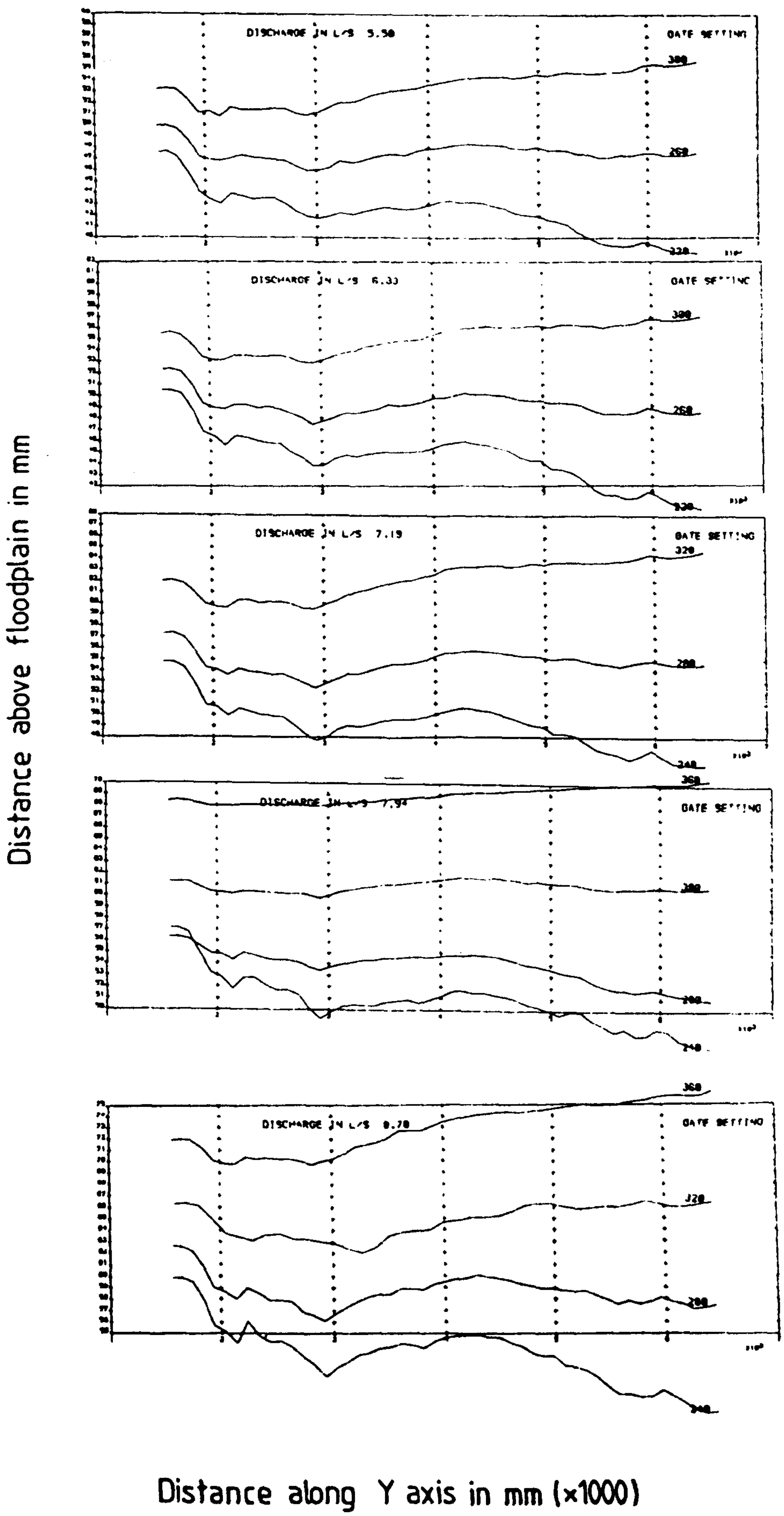

SERIES 1
DISCHARGE IN L/S 6.23
GATE SETTING
240
DISCHARGE IN L/S 7.16
GATE SETTING
260
245
230
215
DISCHARGE IN L/S 8.33
GATE SETTING
250
235
220
DISCHARGE IN L/S 9.13
GATE SETTING
285
265
240
225
DISCHARGE IN L/S 10.20
GATE SETTING
265
250
230
Distance above floodplain in mm
Distance along Y axis in mm (x1000)


SERIES 1
Distance above floodplain in mm
DISCHARGE IN L/S 11.22
DATE SETTING
DISCHARGE IN L/S 12.54
DATE SETTING
DISCHARGE IN L/S 13.48
DATE SETTING
Distance along Y axis in mm (×1000)

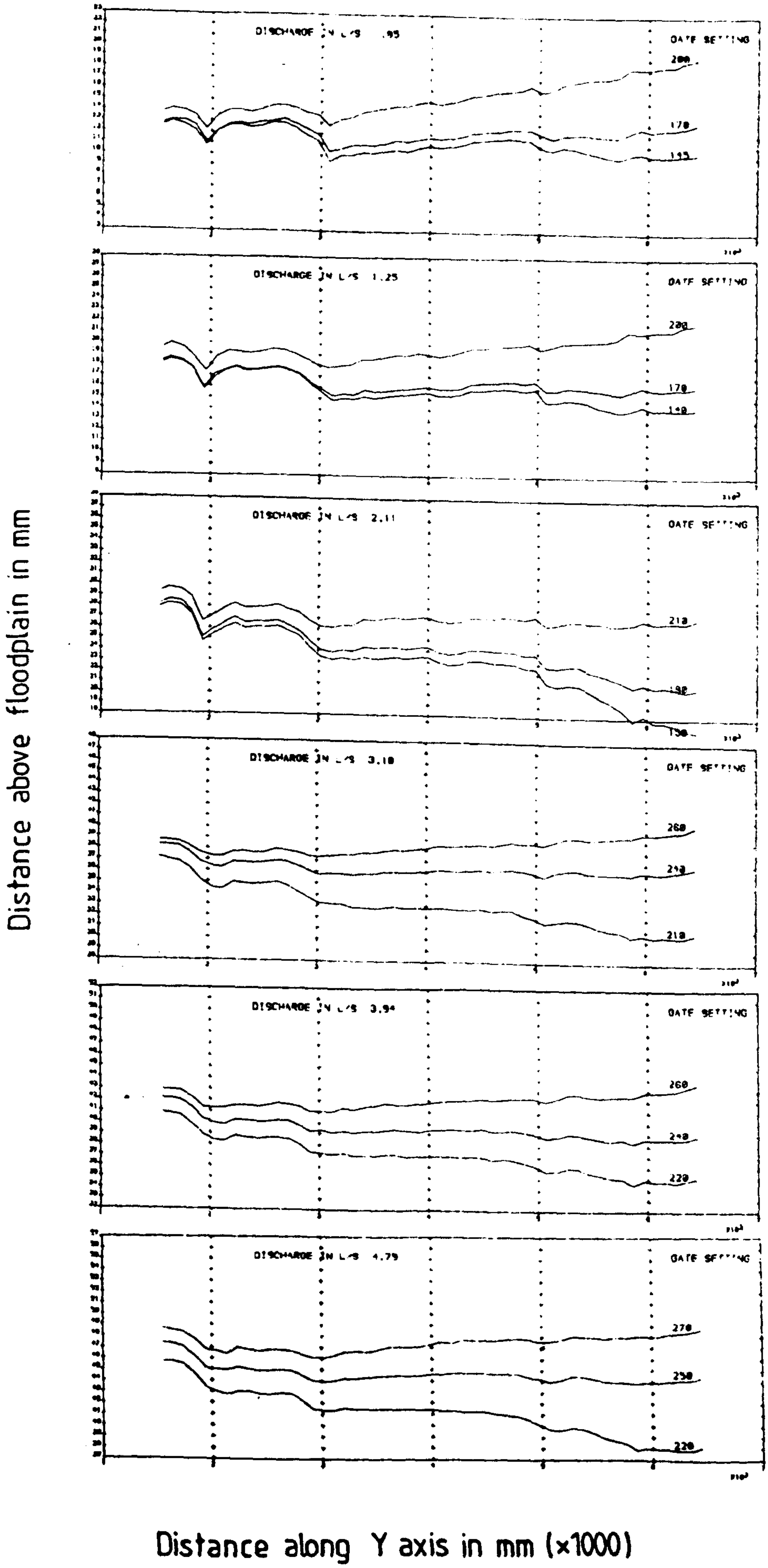
SERIES 2


DISCHARGE IN L/S 1.25
GATE SETTING
DISCHARGE IN L/S 1.52
GATE SETTING
DISCHARGE IN L/S 2.10
GATE SETTING
DISCHARGE IN L/S 2.37
GATE SETTING
DISCHARGE IN L/S 3.94
GATE SETTING
DISCHARGE IN L/S 4.79
GATE SETTING
Distance above floodplain in mm
Distance along Y axis in mm (×1000)

SERIES 2

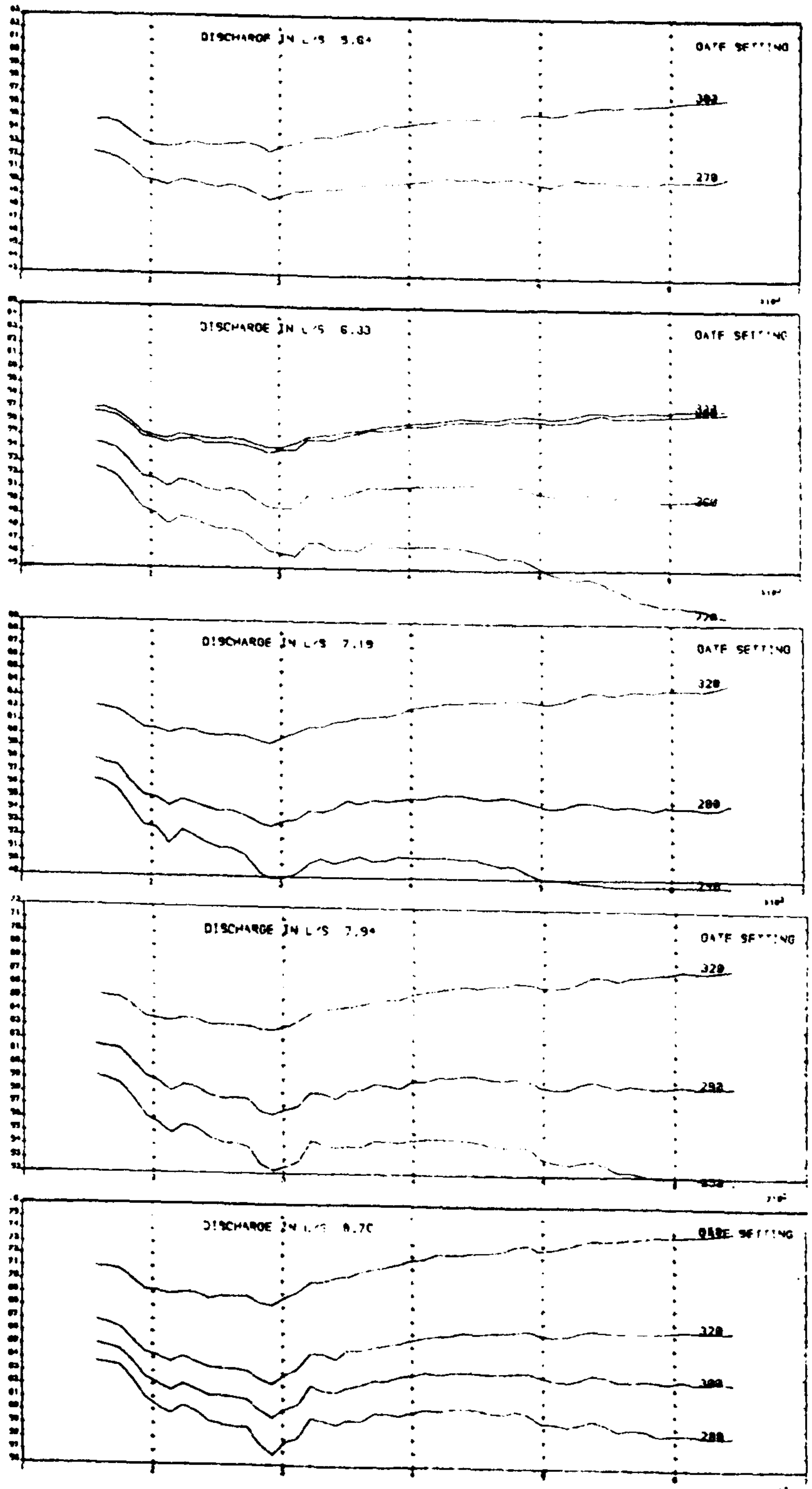

DISCHARGE IN L/S 5.50
GATE SETTING
DISCHARGE IN L/S 6.33
GATE SETTING
DISCHARGE IN L/S 7.19
GATE SETTING
DISCHARGE IN L/S 7.94
GATE SETTING
DISCHARGE IN L/S 8.78
GATE SETTING
Distance above floodplain in mm
Distance along Y axis in mm (x1000)

SERIES 3

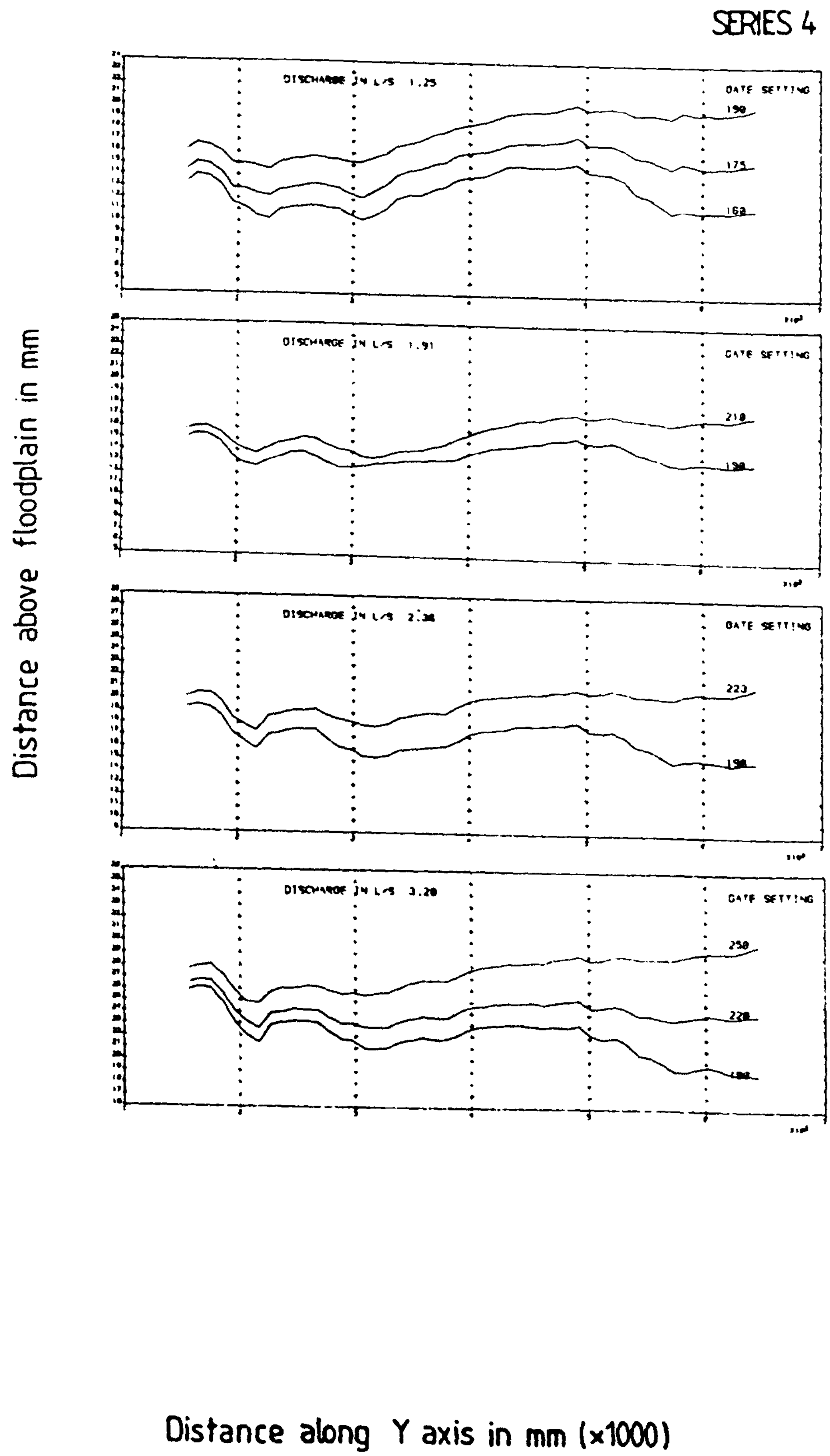

DISCHARGE IN L/S .95
DATE SETTING
200
170
DISCHARGE IN L/S 1.25
DATE SETTING
200
170
DISCHARGE IN L/S 2.11
DATE SETTING
210
DISCHARGE IN L/S 3.10
DATE SETTING
260
210
DISCHARGE IN L/S 3.94
DATE SETTING
260
220
DISCHARGE IN L/S 4.79
DATE SETTING
270
250
220
Distance above floodplain in mm
Distance along Y axis in mm (x1000)

SERIES 3

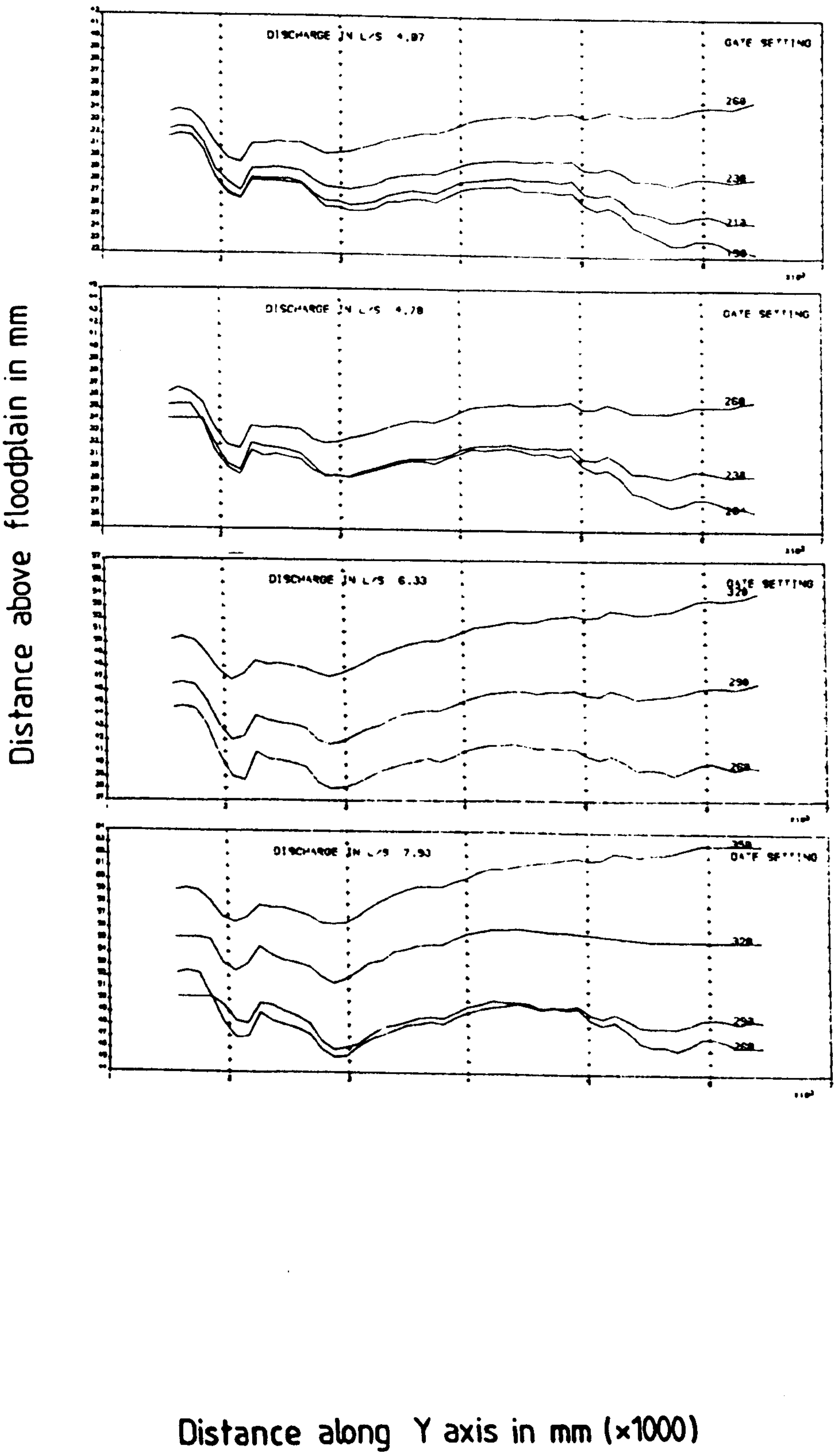
Distance above floodplain in mm



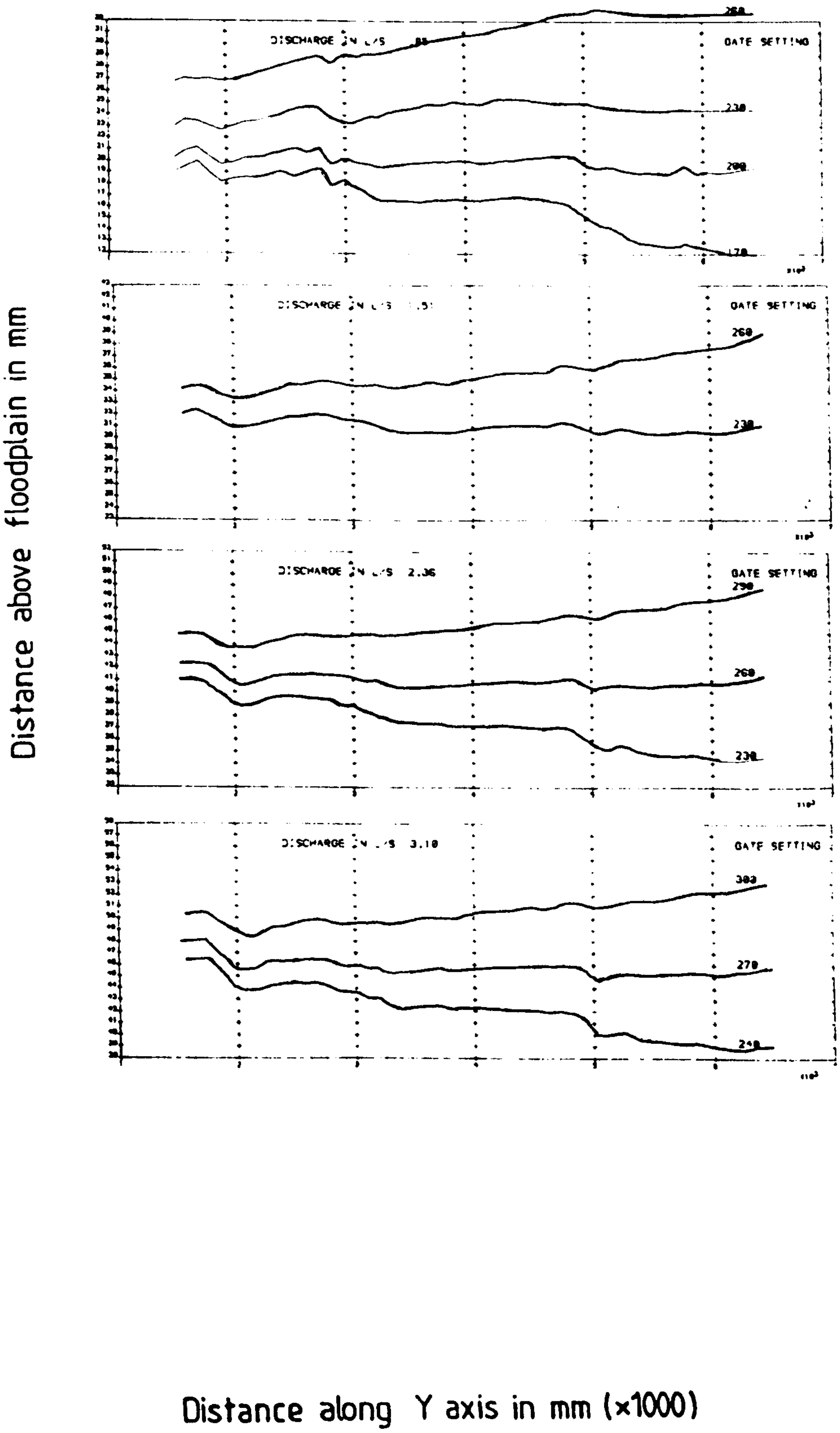
Distance along Y axis in mm (×1000)

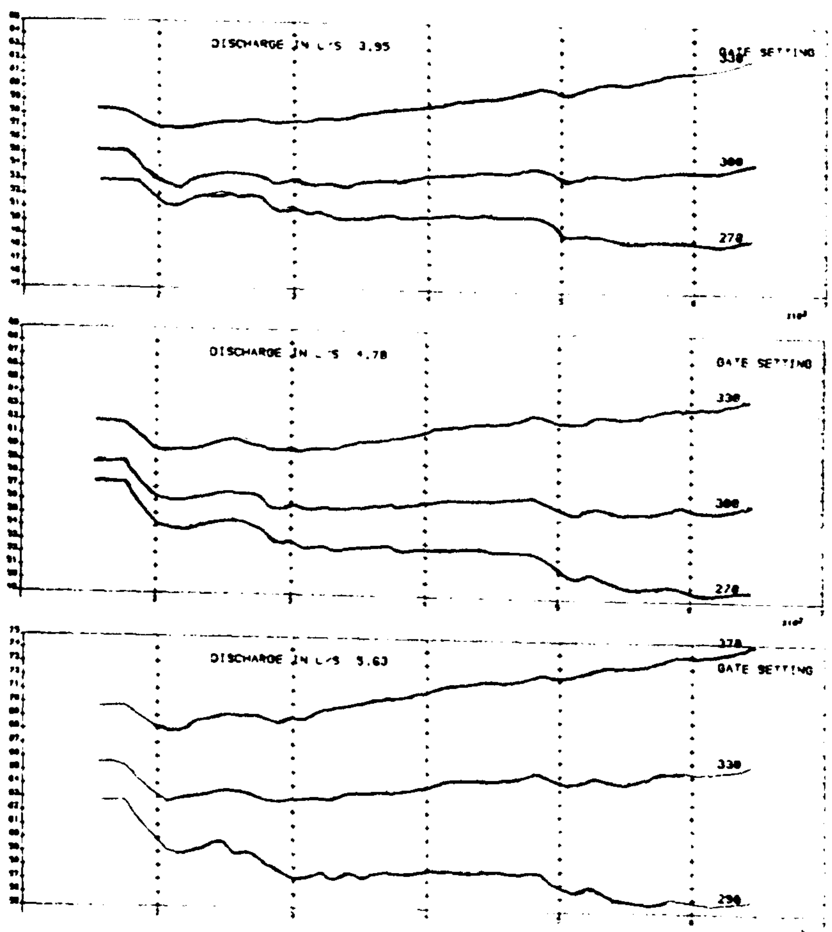

SERIES 4
Distance above floodplain in mm
DISCHARGE IN L/S 1.25
DATE SETTING
190
175
160
DISCHARGE IN L/S 1.91
DATE SETTING
210
190
DISCHARGE IN L/S 2.38
DATE SETTING
223
190
DISCHARGE IN L/S 3.20
DATE SETTING
250
220
190
Distance along Y axis in mm (x1000)

SERIES 4


DISCHARGE IN L/S 4.87
GATE SETTING
DISCHARGE IN L/S 4.78
GATE SETTING
DISCHARGE IN L/S 6.33
GATE SETTING
DISCHARGE IN L/S 7.93
GATE SETTING
Distance above floodplain in mm
Distance along Y axis in mm (×1000)

SERIES 5


GATE SETTING
260
230
200
170
GATE SETTING
260
230
DISCHARGE IN L/S 2.36
GATE SETTING
290
260
230
DISCHARGE IN L/S 3.10
GATE SETTING
300
270
240
Distance above floodplain in mm
Distance along Y axis in mm (x1000)

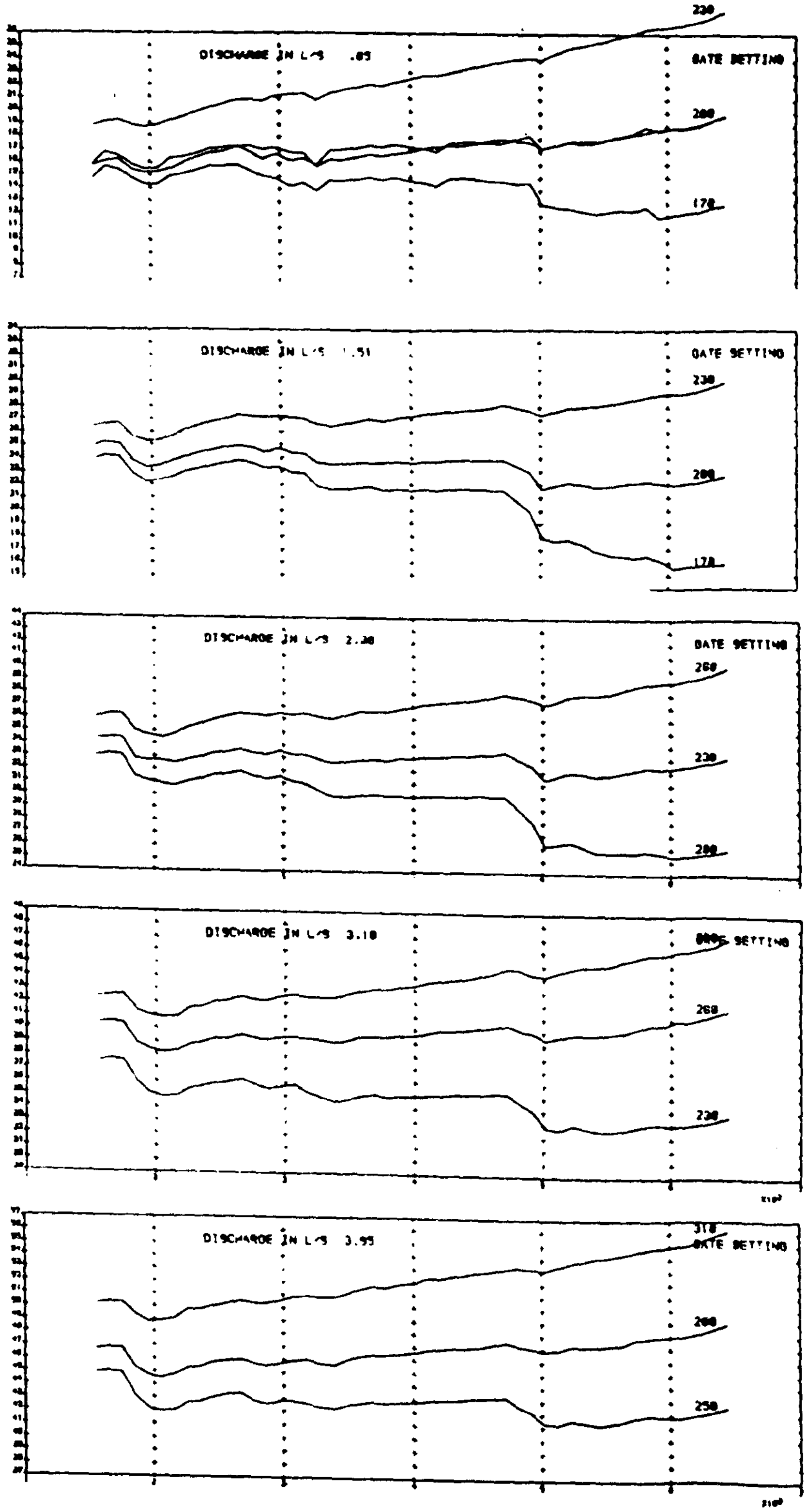


Distance above floodplain in mm

Distance along Y axis in mm (x1000)

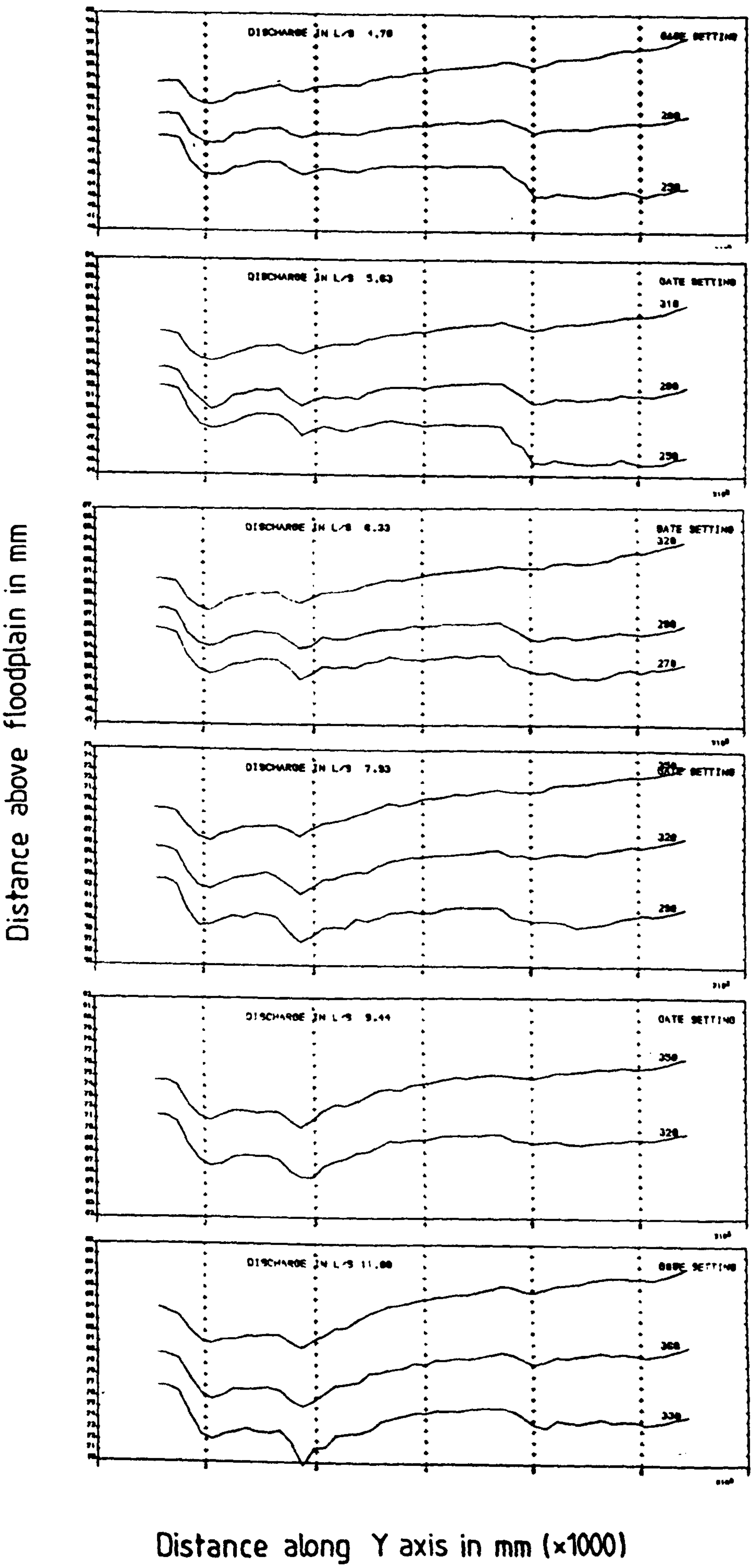
SERES 6

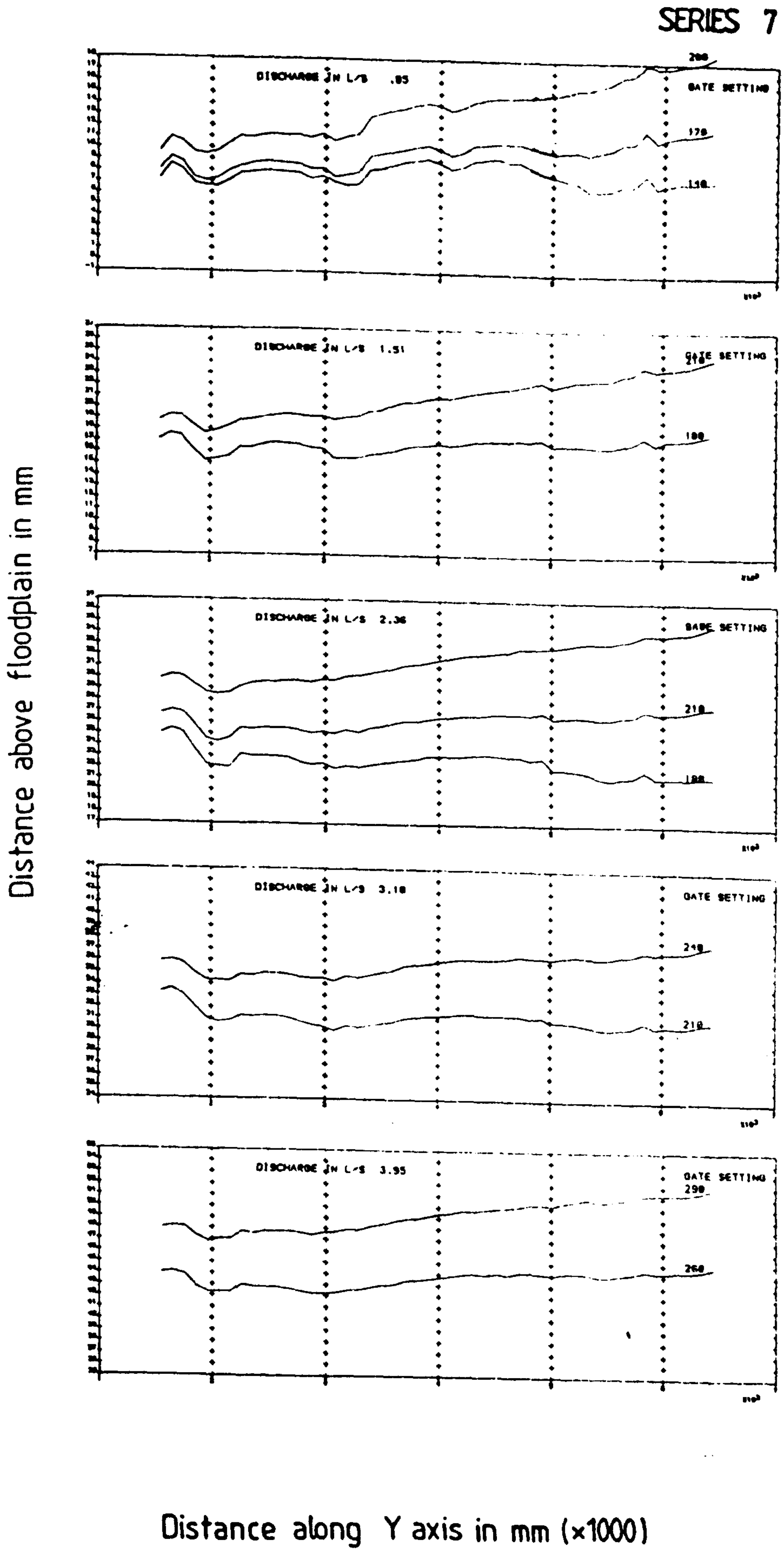
Distance above floodplain in mm



Distance along Y axis in mm (×1000)

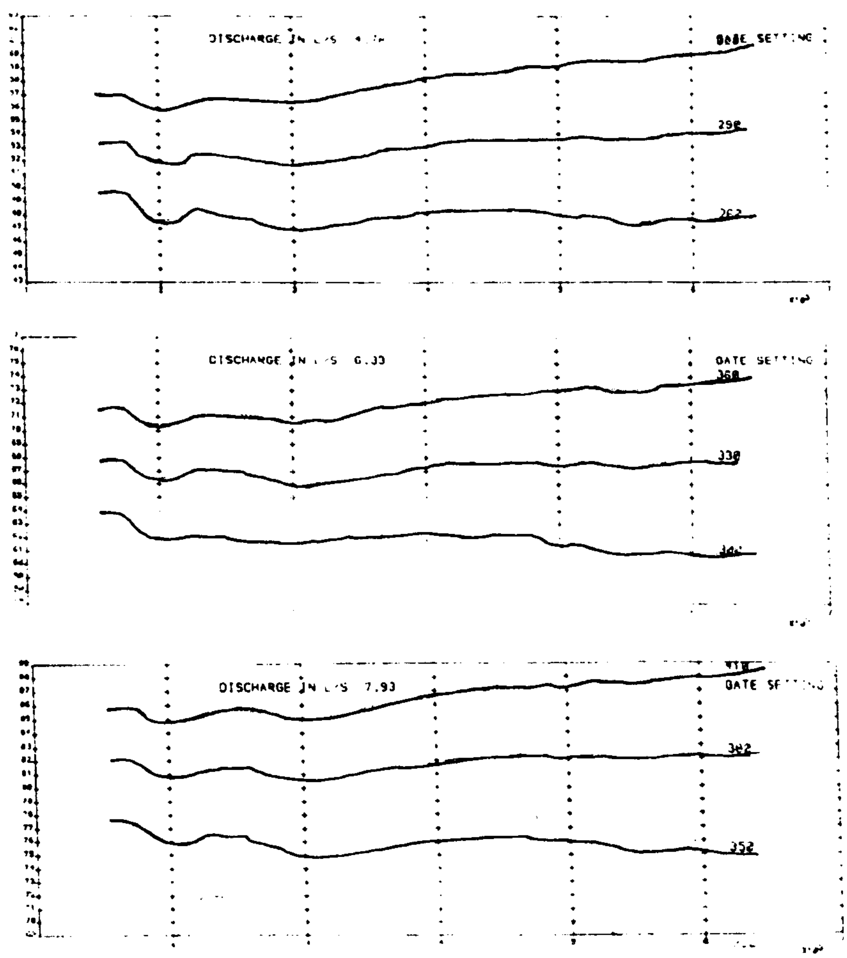
SERIES 6


Distance above floodplain in mm
DISCHARGE IN L/S 4.70
GATE SETTING
DISCHARGE IN L/S 5.63
GATE SETTING
310
DISCHARGE IN L/S 6.33
GATE SETTING
320
290
270
DISCHARGE IN L/S 7.93
GATE SETTING
320
DISCHARGE IN L/S 9.44
GATE SETTING
350
320
GATE SETTING
360
330
Distance along Y axis in mm (x1000)

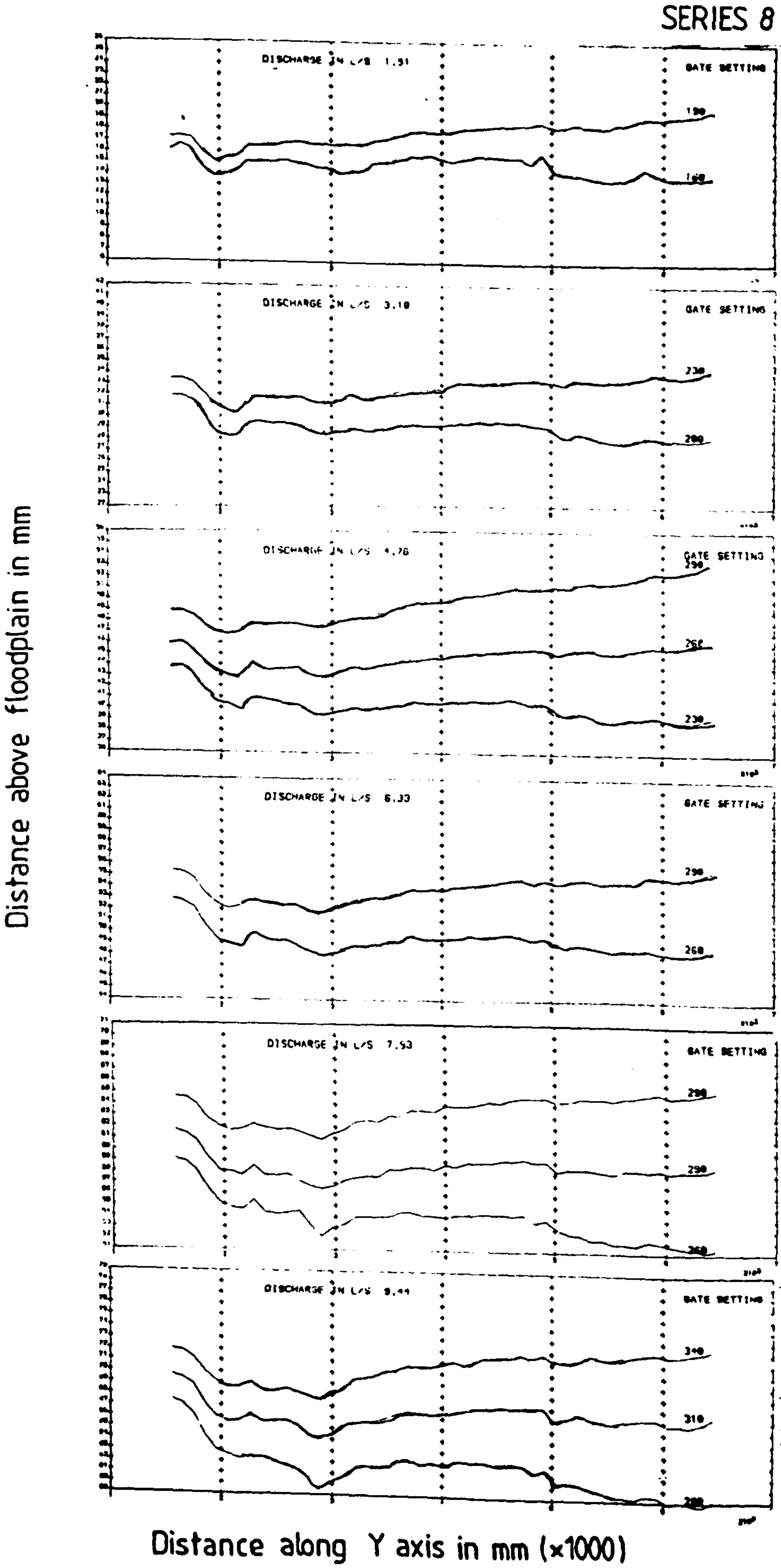

SERIES 7
DISCHARGE IN L/S .85
GATE SETTING
DISCHARGE IN L/S 1.51
GATE SETTING
DISCHARGE IN L/S 2.36
GATE SETTING
DISCHARGE IN L/S 3.18
GATE SETTING
DISCHARGE IN L/S 3.95
GATE SETTING
Distance above floodplain in mm
Distance along Y axis in mm (×1000)

SERIES 7

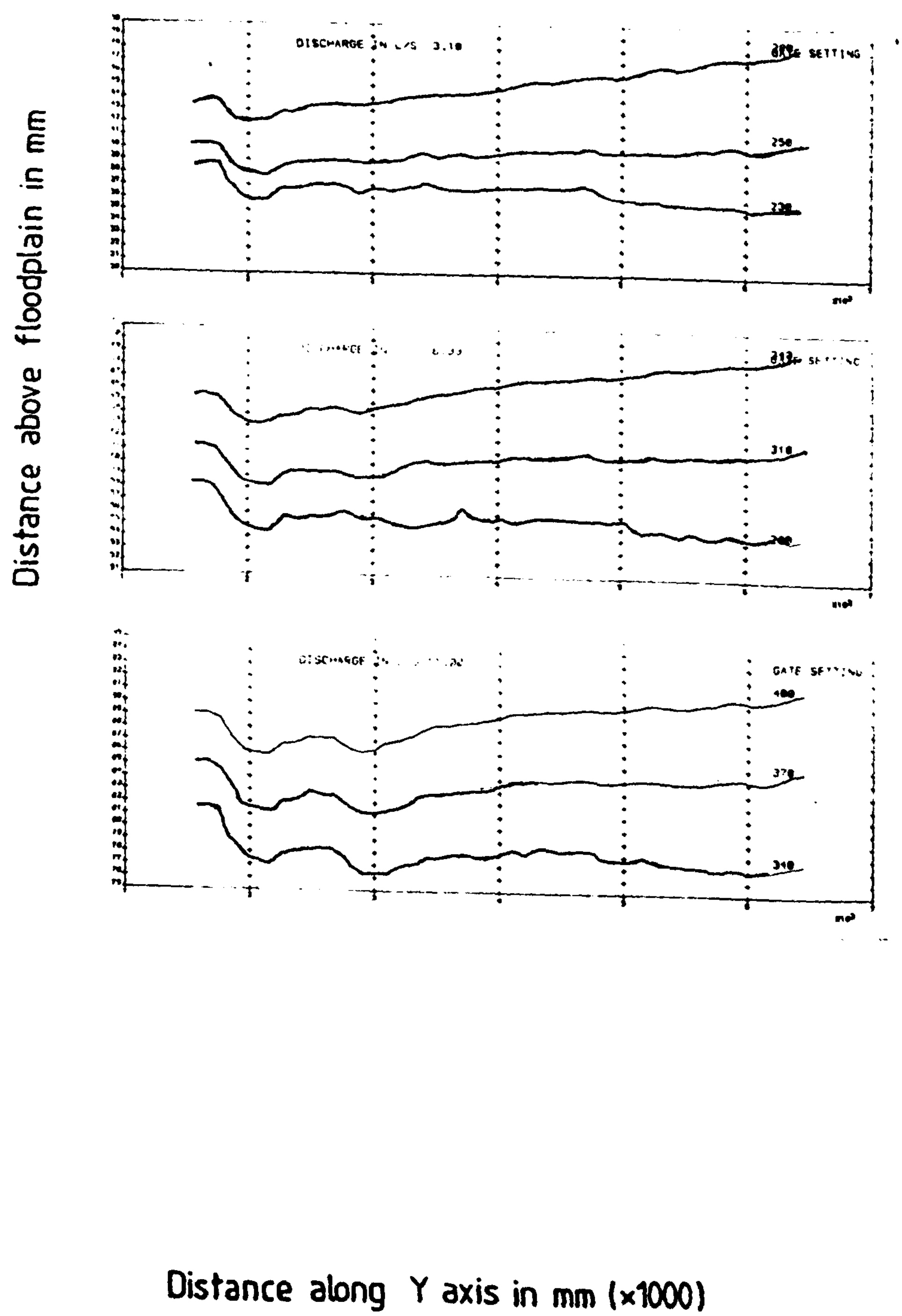
Distance above floodplain in mm



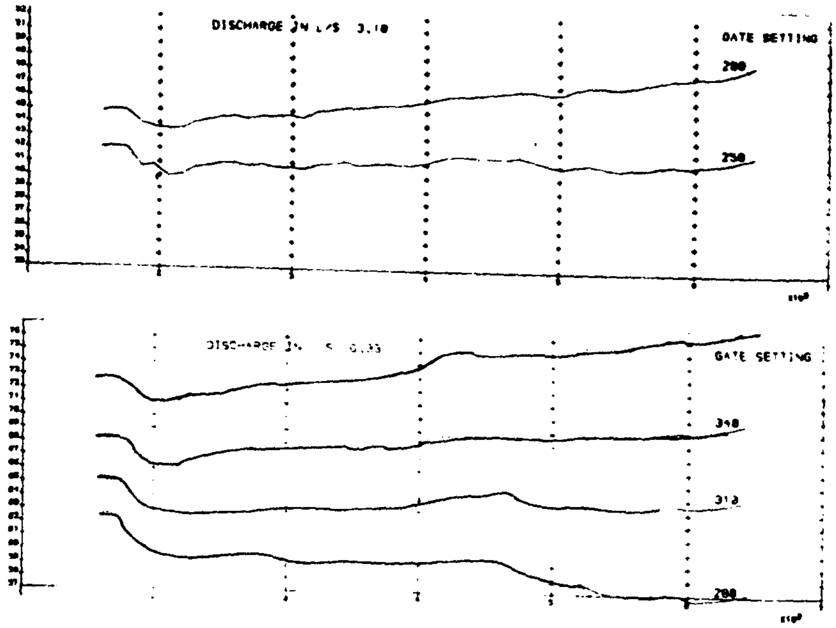
Distance along Y axis in mm (×1000)


SERIES 8
Distance above floodplain in mm
Distance along Y axis in mm (×1000)

R 1

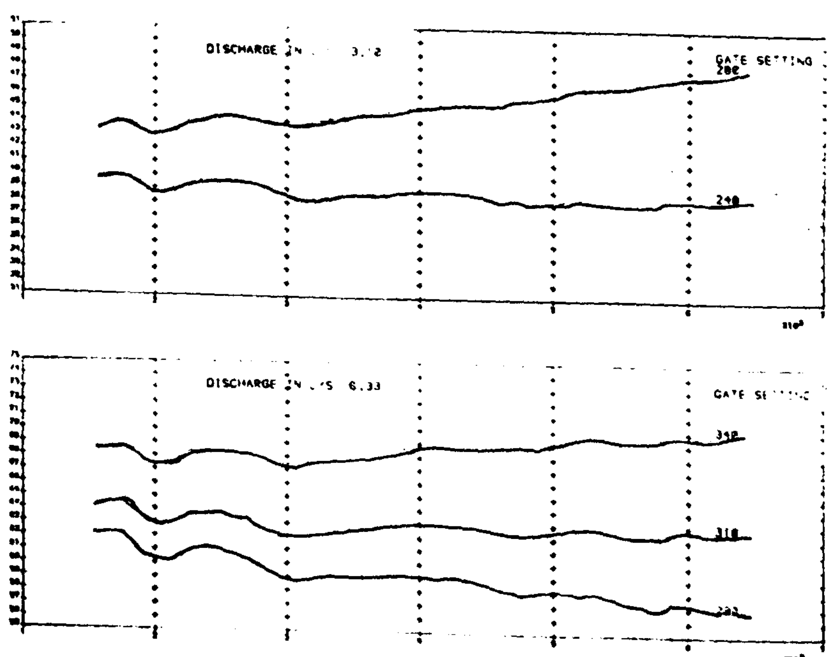

Distance above floodplain in mm
DISCHARGE IN L/S 3.10
GATE SETTING
250
310
400
370
340
Distance along Y axis in mm (×1000)

R2

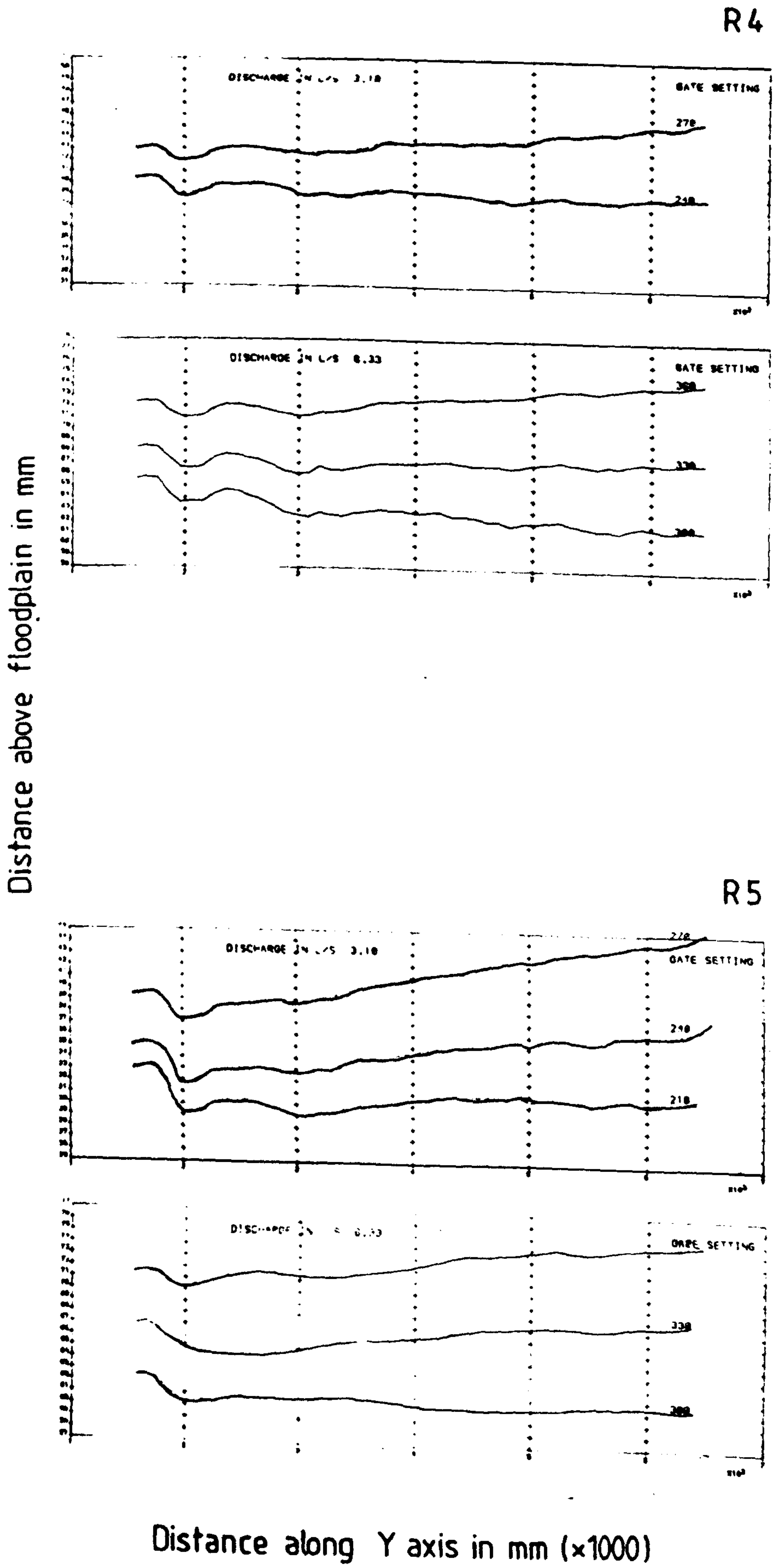


Distance above floodplain in mm

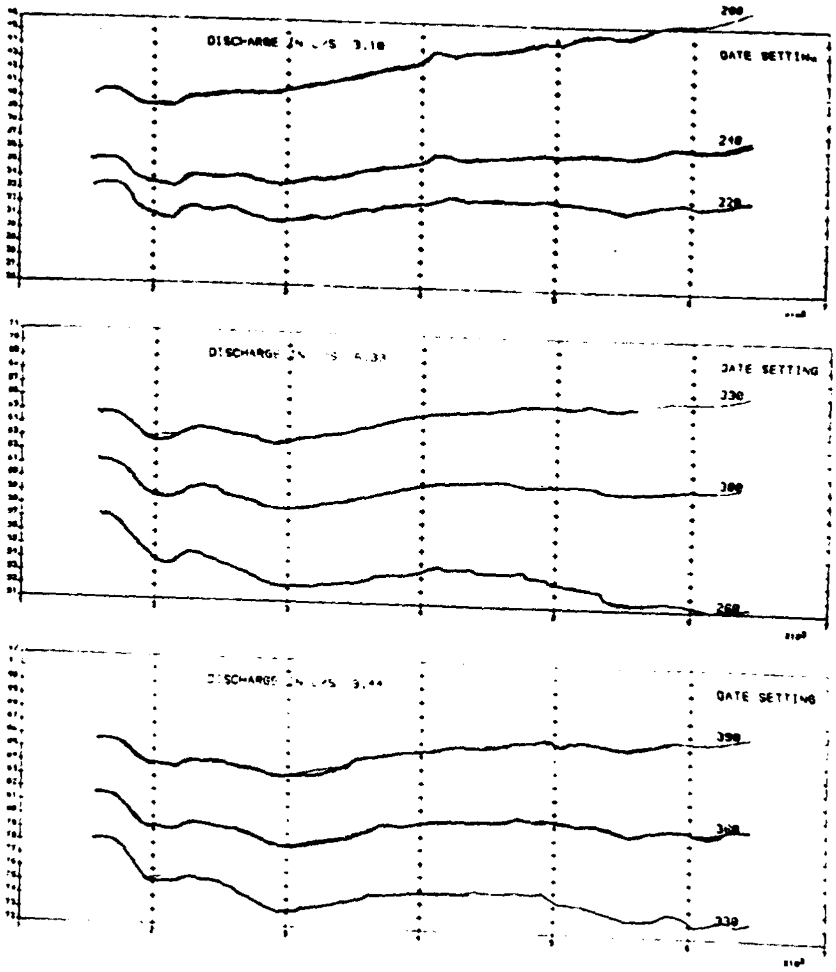
R3



Distance along Y axis in mm (x1000)

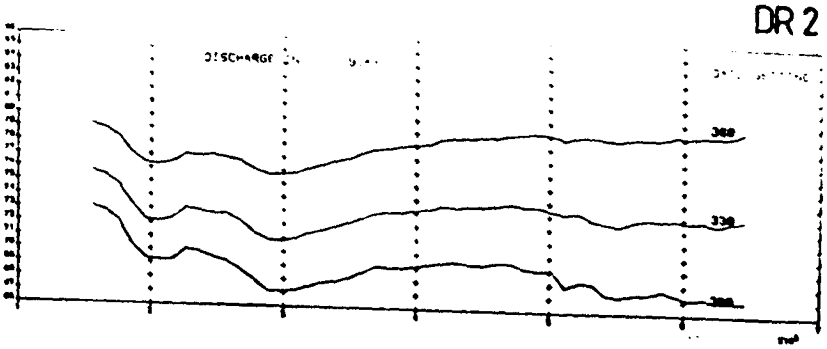

R4
DISCHARGE IN L/S 3.10
GATE SETTING
270
210
DISCHARGE IN L/S 6.33
GATE SETTING
360
330
300
Distance above floodplain in mm
R5
DISCHARGE IN L/S 3.10
GATE SETTING
240
210
330
300
Distance along Y axis in mm (×1000)

DR 1



Distance above floodplain in mm

DR 2



Distance along Y axis in mm (×1000)

SERIES 1
ROUGHNESS: F1 M1

DISCHARGE (L/S)	NORMAL DEPTH (MM)
1.87	11
.93	3
.82	0
.71	-2
.60	-6
.51	-9
.40	-12
1.68	10
1.45	7
2.69	16
3.50	21
3.29	20
8.33	46
12.54	60
11.22	59
13.41	64
9.11	47
10.28	53
5.98	35
5.80	35
4.29	27
4.11	24
4.54	30

SERIES 2
ROUGHNESS: F2 M2

DISCHARGE(L/S)	NORMAL DEPTH(MM)
.39	-7
.58	-2
.91	2
1.25	13
1.52	16
2.37	24
3.10	32
3.94	39
4.79	45
5.64	49
6.33	52
7.18	59
7.93	61
8.78	62

SERIES 3
ROUGHNESS: F2 M3

DISCHARGE(L/S)	NORMAL DEPTH(MM)
.21	0
.85	12
1.25	16
2.10	27
3.10	36
3.94	40
4.79	44
5.64	50
6.33	52
7.18	56
7.94	60
8.78	63

SERIES 4
ROUGHNESS: F3 M1

DISCHARGE(L/S)	NORMAL DEPTH(MM)
.4	-12
.6	-6
.8	0
1.25	20
1.91	27
2.36	31
3.20	37
4.07	42
4.78	45
6.33	56
7.93	68

SERIES 5
ROUGHNESS: F4 M4

DISCHARGE(L/S)	NORMAL DEPTH(MM)
.85	25
1.51	32
2.36	41
3.10	46
3.95	53
4.78	56
5.63	62

SERIES 6
ROUGHNESS: F5 M4

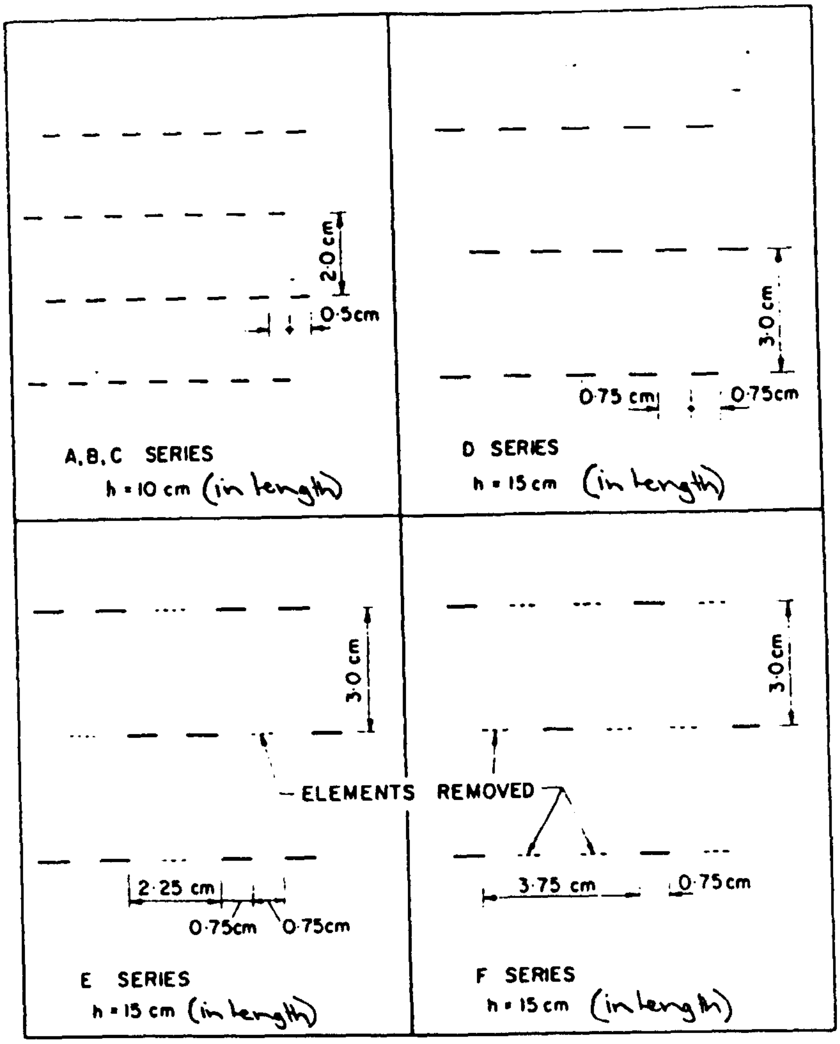
DISCHARGE(L/S)	NORMAL DEPTH(MM)
.85	16
1.51	25
2.36	33
3.10	38
3.95	44
4.78	48
5.63	52
6.33	55
7.93	60
9.44	69
11.0	76

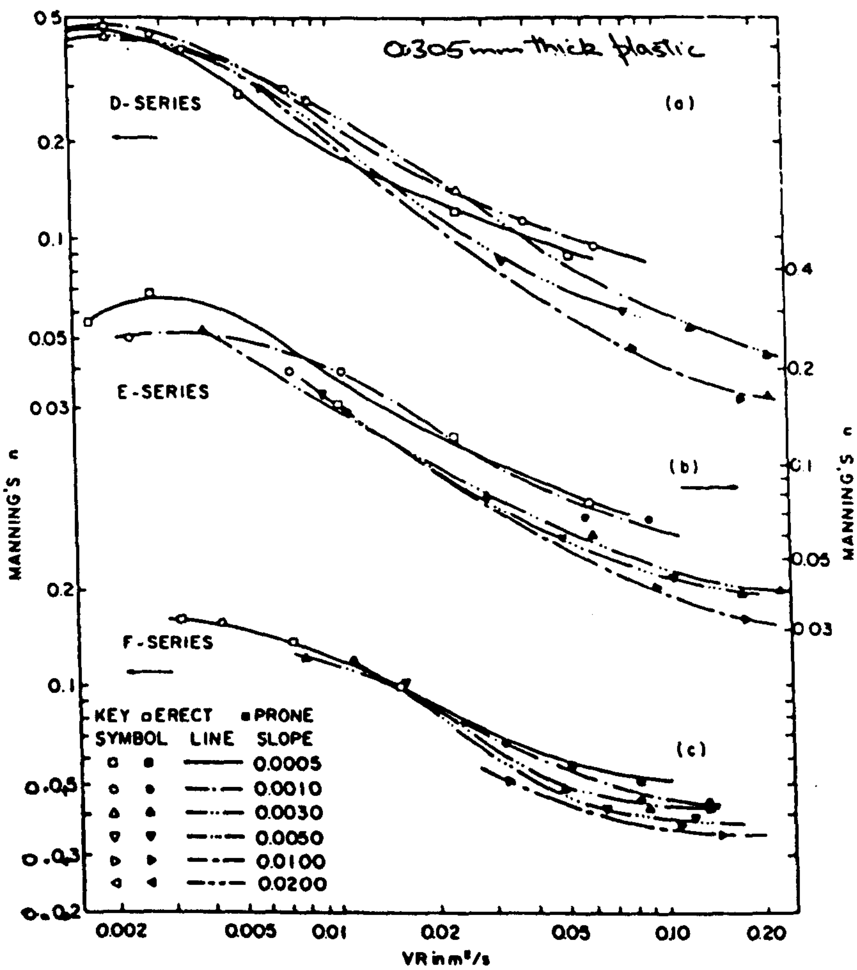
SERIES 7
ROUGHNESS: F11 M6

DISCHARGE(L/S)	NORMAL DEPTH(MM)
.85	9
1.51	17
2.36	26
3.10	32
3.95	42
4.78	50
6.33	67
7.93	82

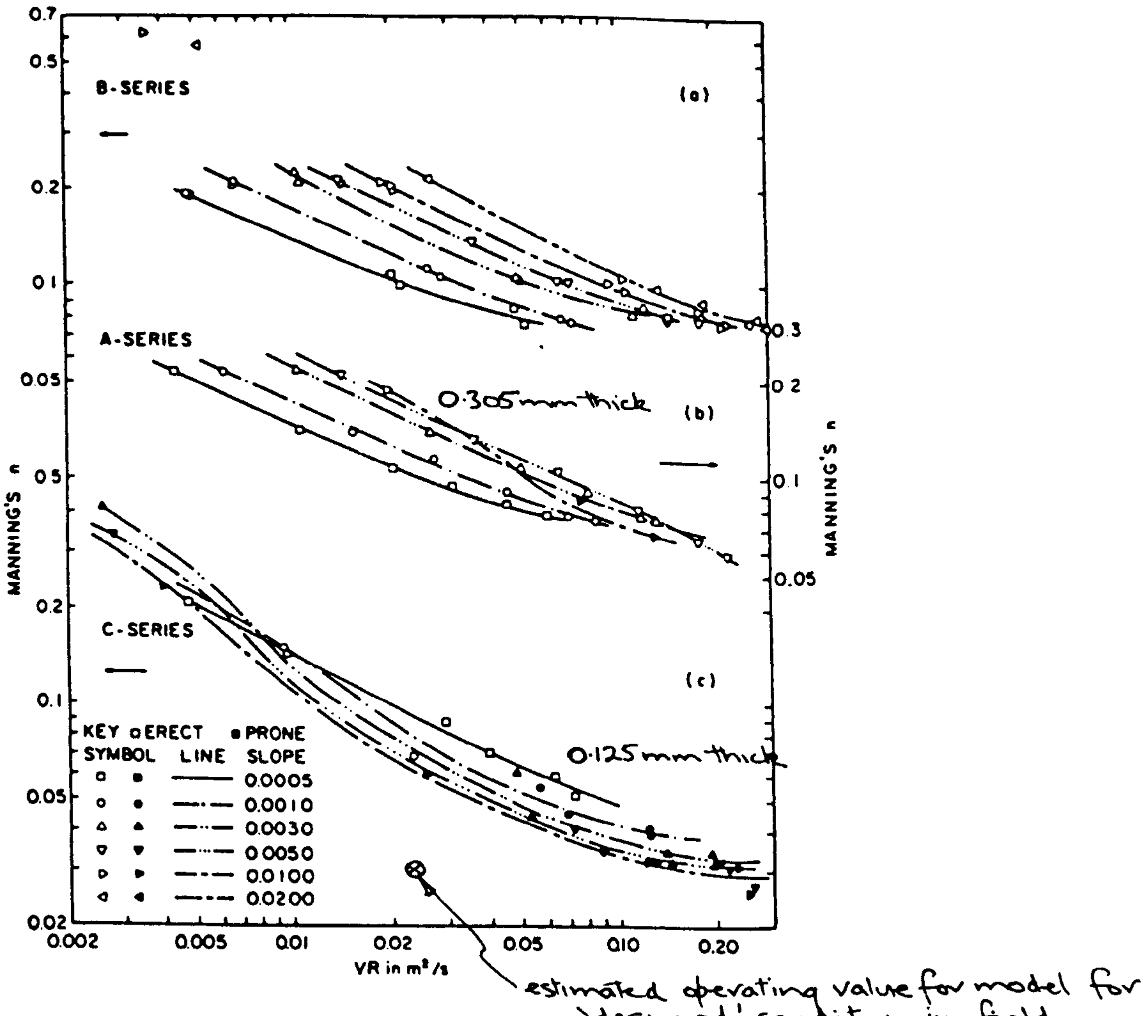
SERIES 8
ROUGHNESS: F14 M6

DISCHARGE(L/S)	NORMAL DEPTH(MM)
1.51	17
3.10	32
4.78	43
6.33	53
7.93	61
9.44	68



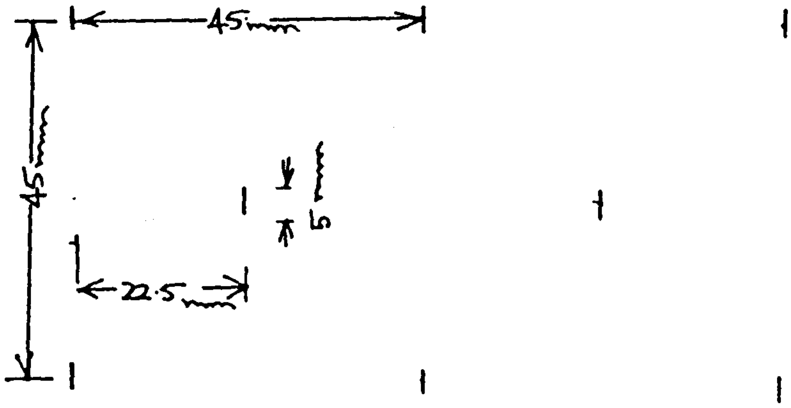


Effect of Spacing on Retardance Curves

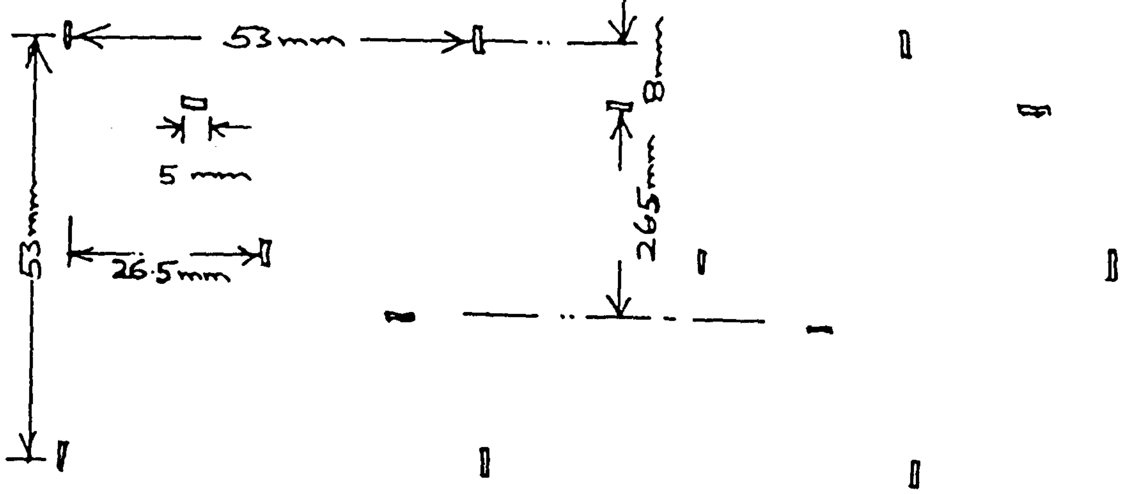


Effect of Stiffness on Retardance Curves

Illustrations of Different Roughness Configurations Used



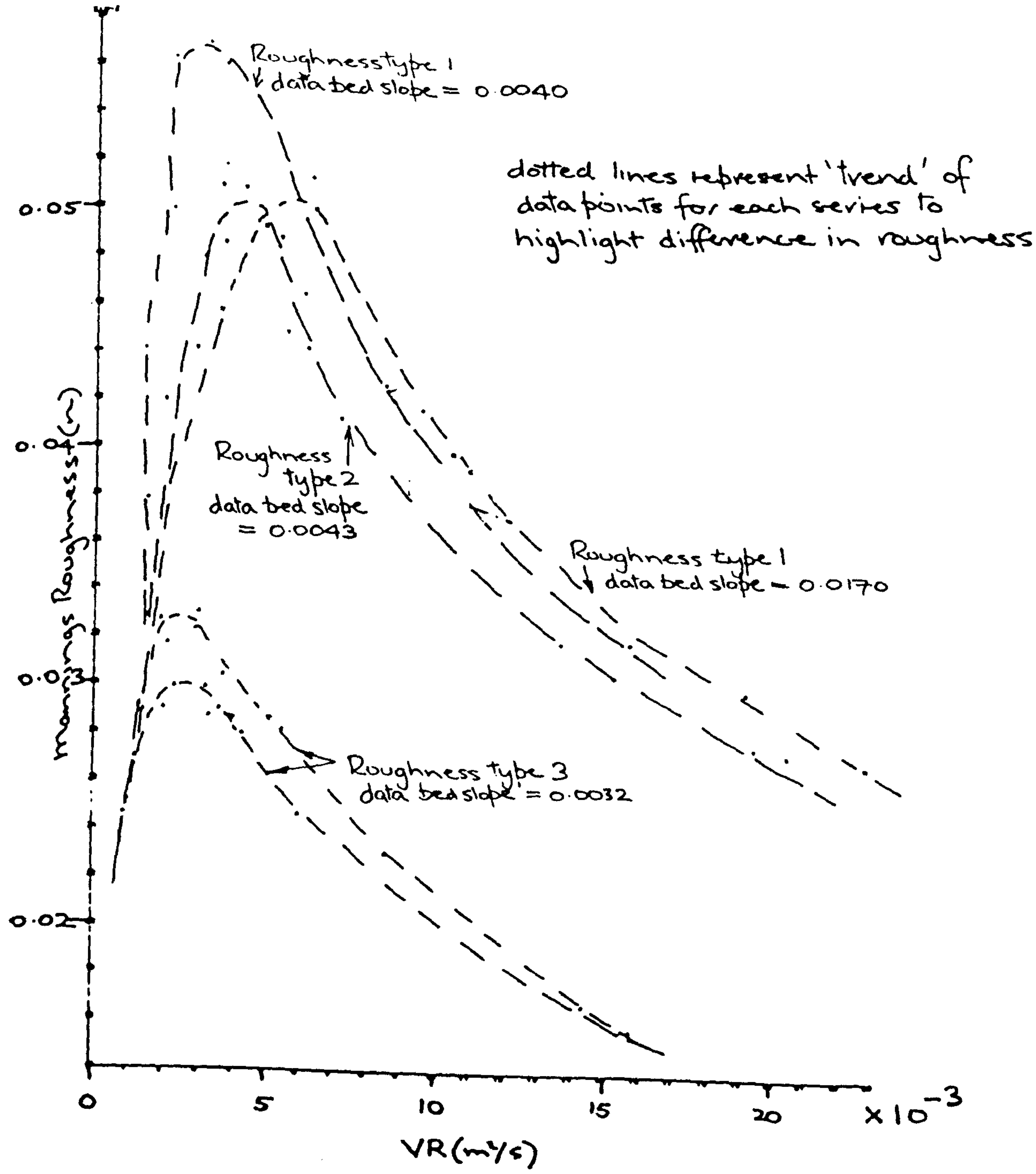
(FX1) ROUGHNESS TYPE 1 – 40/45/45/5 length 40mm
sheet thickness 0.13mm



ROUGHNESS TYPE-2 – 40/53/53/5-D length 40mm
sheet thickness 0.13mm

Configuration as above

ROUGHNESS TYPE 3 – 40/53/53/5-D(2) length 40mm
sheet thickness 0.05mm


Roughness type 1
data bed slope = 0.0040
dotted lines represent 'trend' of
data points for each series to
highlight difference in roughness
0.05
0.04
0.03
0.02
Mannings Roughness (n)
Roughness
type 2
data bed slope
= 0.0043
Roughness type 1
data bed slope = 0.0170
Roughness type 3
data bed slope = 0.0032
0
5
10
15
20
× 10⁻³
VR (m²/s)

SERIES 7

h (mm)	Q (L/s)	A (m^2)	P (m)
0	0.4	.0072	.49
10	1.0	.0129	.91
20	1.8	.0187	.93
30	2.3	.0247	.96
40	3.8	.0308	.98
50	4.8	.0371	1.01
60	5.7	.0436	1.03
70	6.7	.0502	1.06

SERIES 8

0	0.4	.0072	.49
10	1.0	.0129	.91
20	1.8	.0187	.93
30	2.4	.0247	.96
40	4.3	.0308	.98
50	5.8	.0371	1.01
60	7.7	.0436	1.03
70	9.8	.0502	1.06

SERIES 7

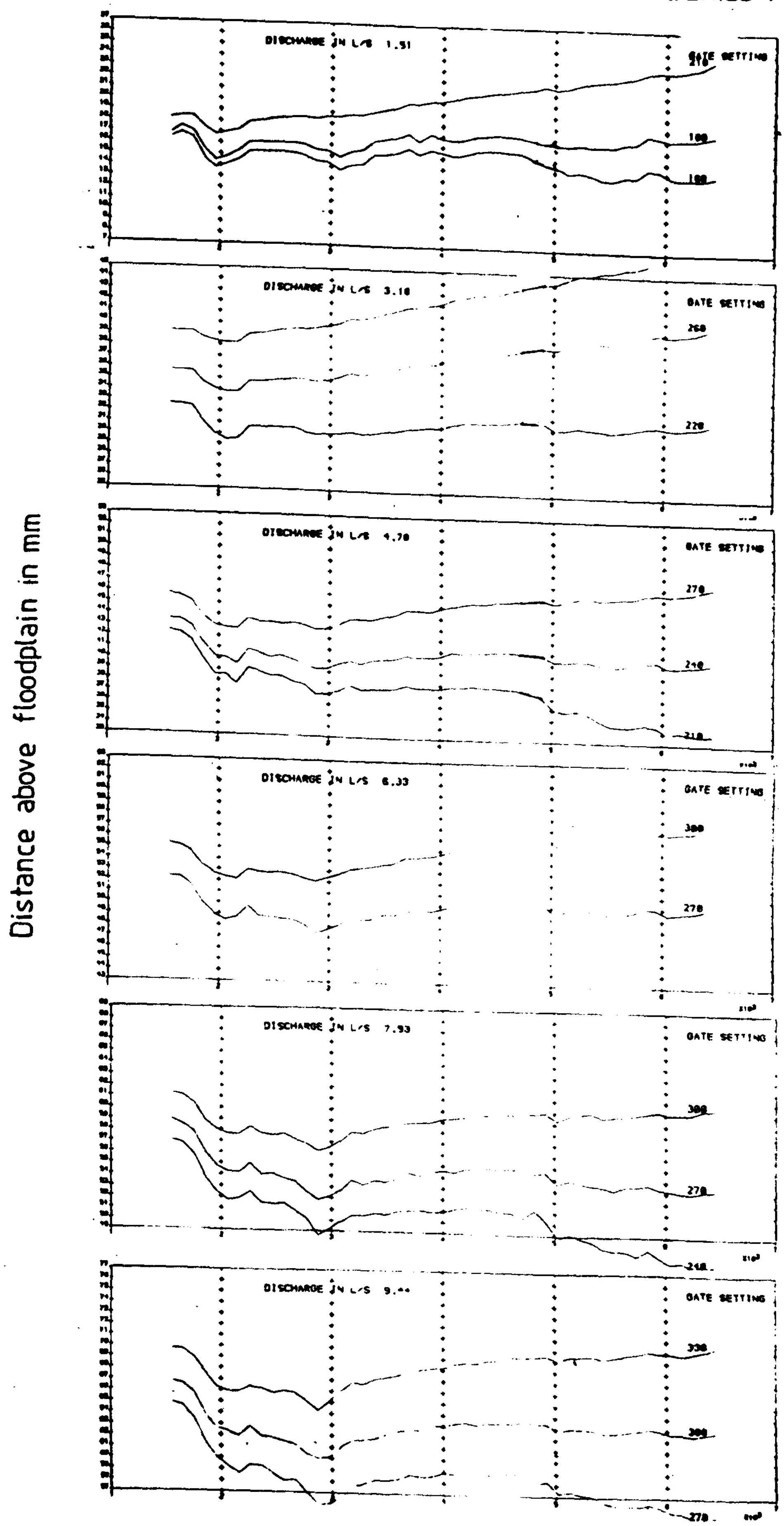
depth above f/plain mm	V (m/s)	R (m)	Re	'n'	λ	k_s(m)
0.00	0.06	0.01	3265	0.062	1.23	0.08
10.00	0.08	0.01	4395	0.043	0.61	0.05
20.00	0.10	0.02	7741	0.044	0.56	0.06
30.00	0.09	0.03	9583	0.054	0.77	0.10
40.00	0.12	0.03	15510	0.046	0.53	0.10
50.00	0.13	0.04	19009	0.049	0.57	0.12
60.00	0.13	0.04	22135	0.053	0.64	0.15
70.00	0.13	0.05	25283	0.056	0.69	0.17

SERIÈS 8

0.00	0.06	0.01	3265	0.062	1.23	0.08
10.00	0.08	0.01	4395	0.043	0.61	0.05
20.00	0.10	0.02	7741	0.044	0.56	0.06
30.00	0.10	0.03	10000	0.052	0.71	0.10
40.00	0.14	0.03	17551	0.041	0.42	0.08
50.00	0.16	0.04	22970	0.041	0.39	0.09
60.00	0.18	0.04	29902	0.040	0.35	0.09
70.00	0.20	0.05	36981	0.039	0.32	0.09

APPENDIX A.7

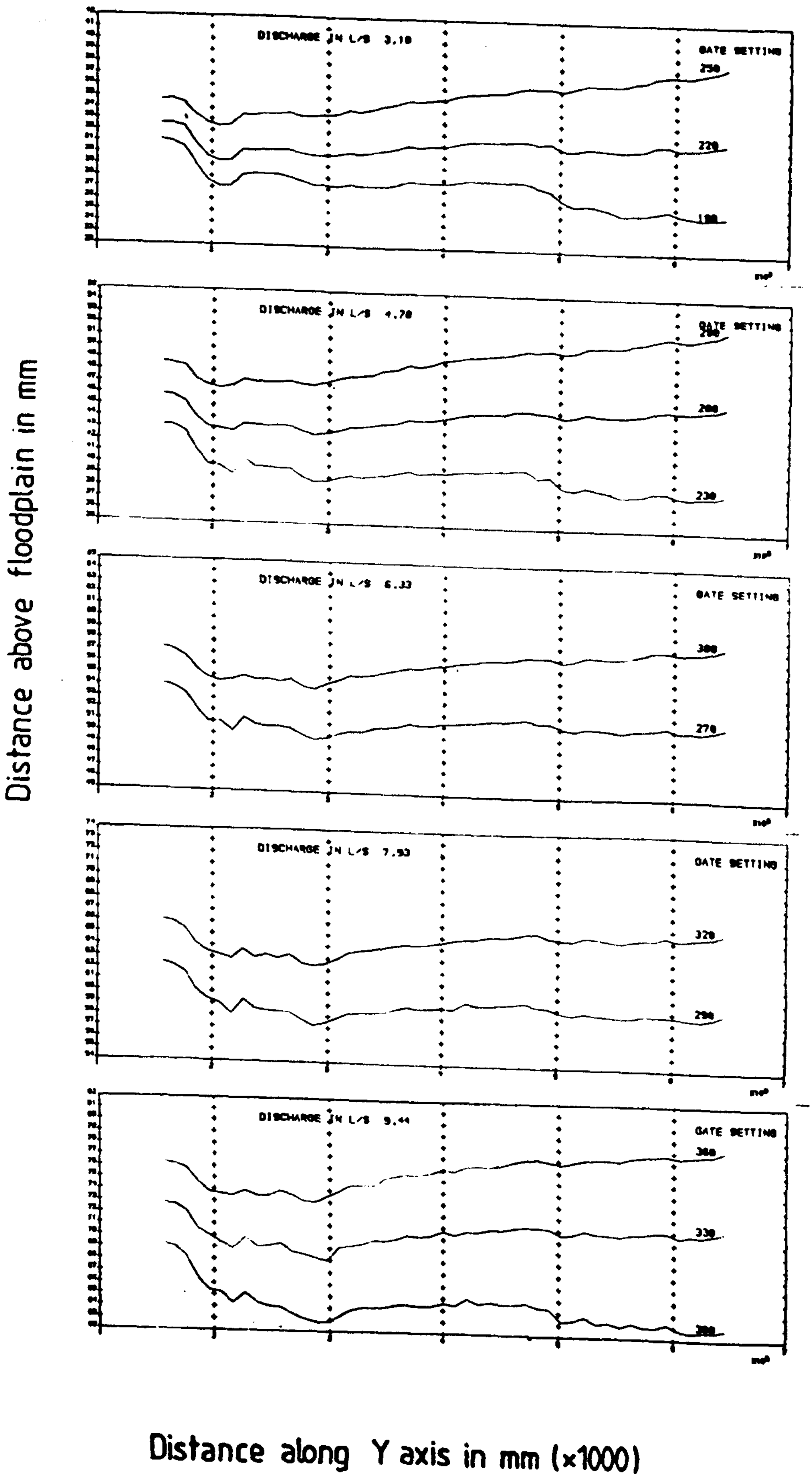
SERIES 9

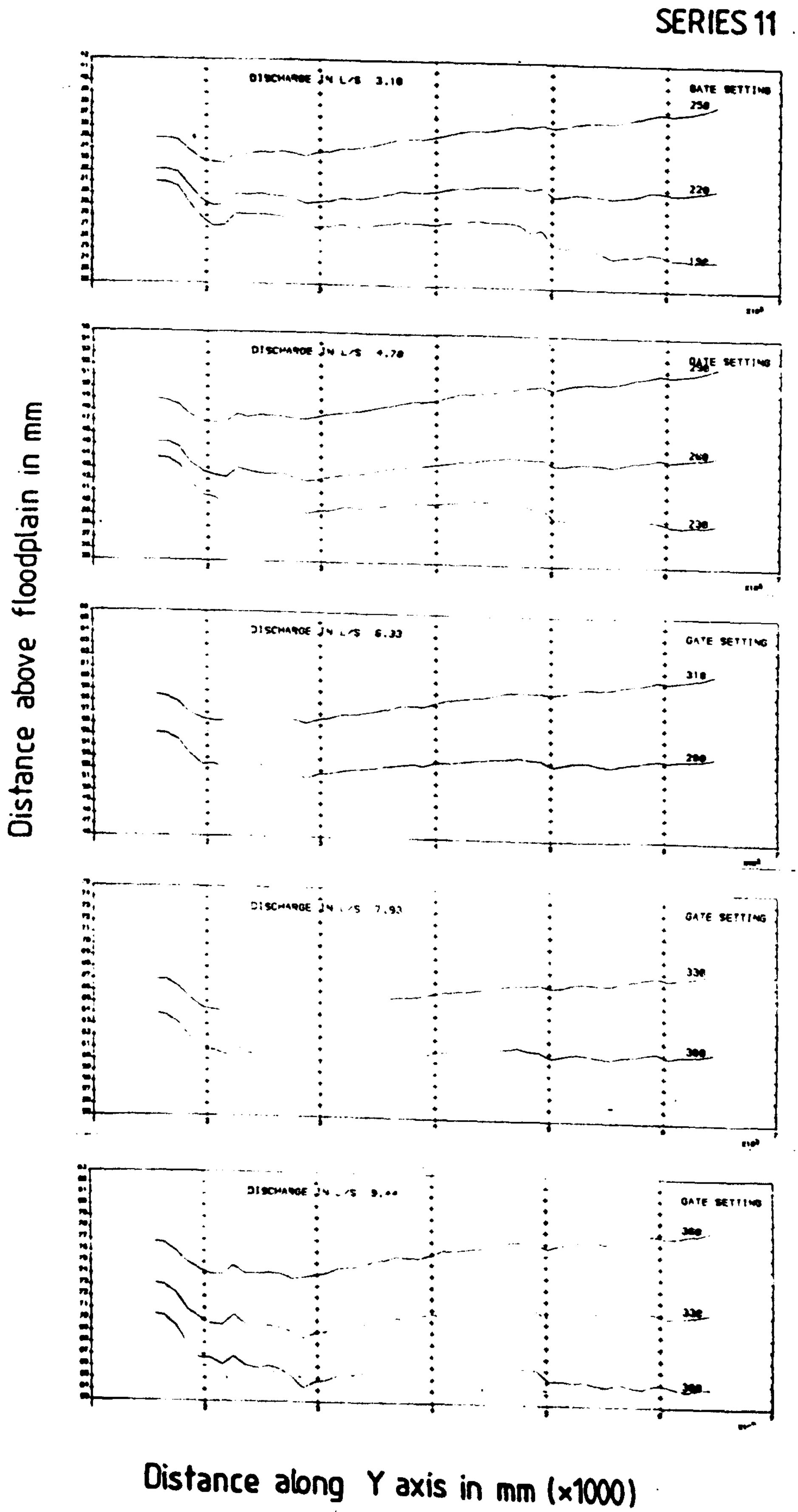


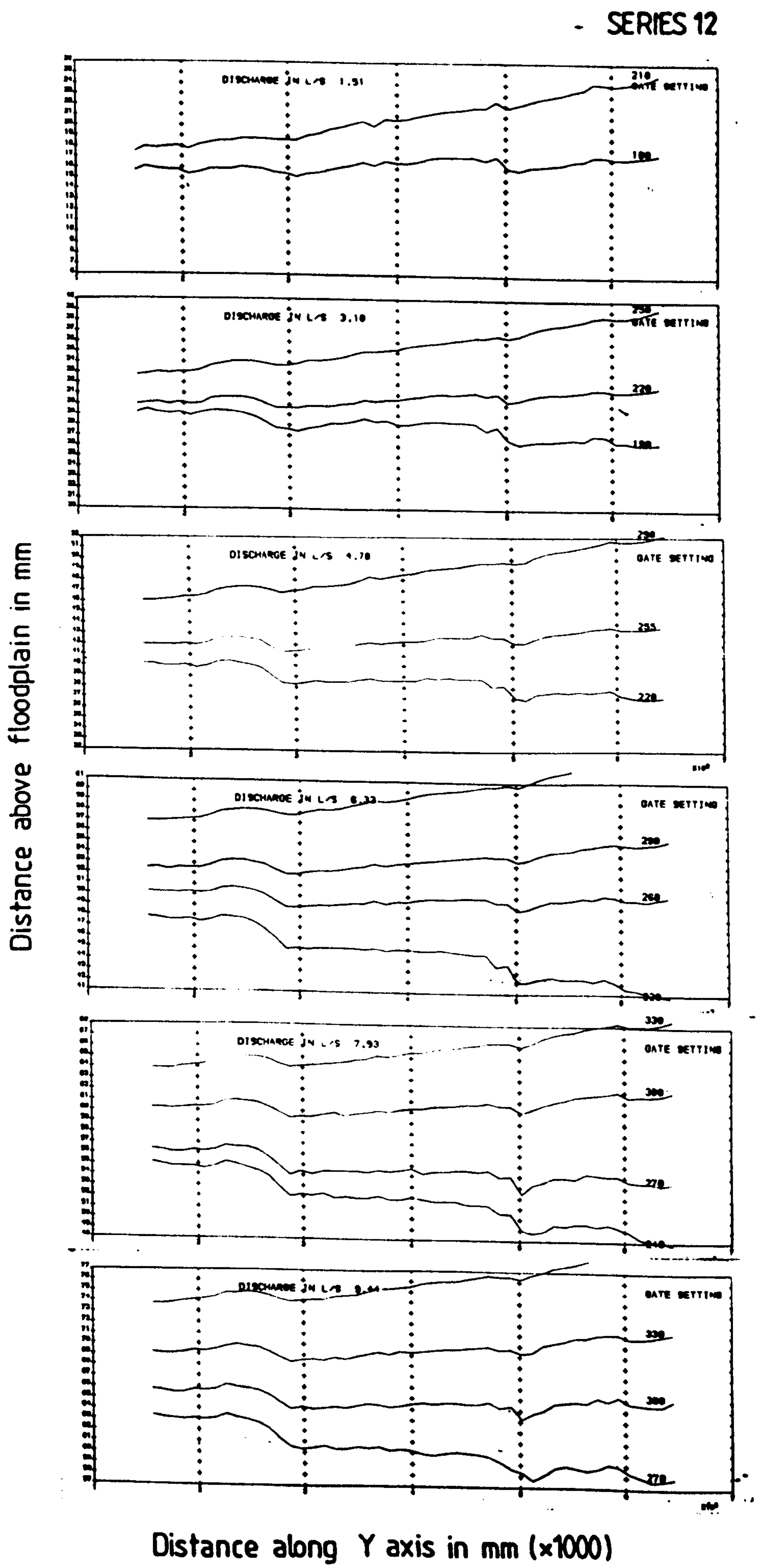
Distance above floodplain in mm

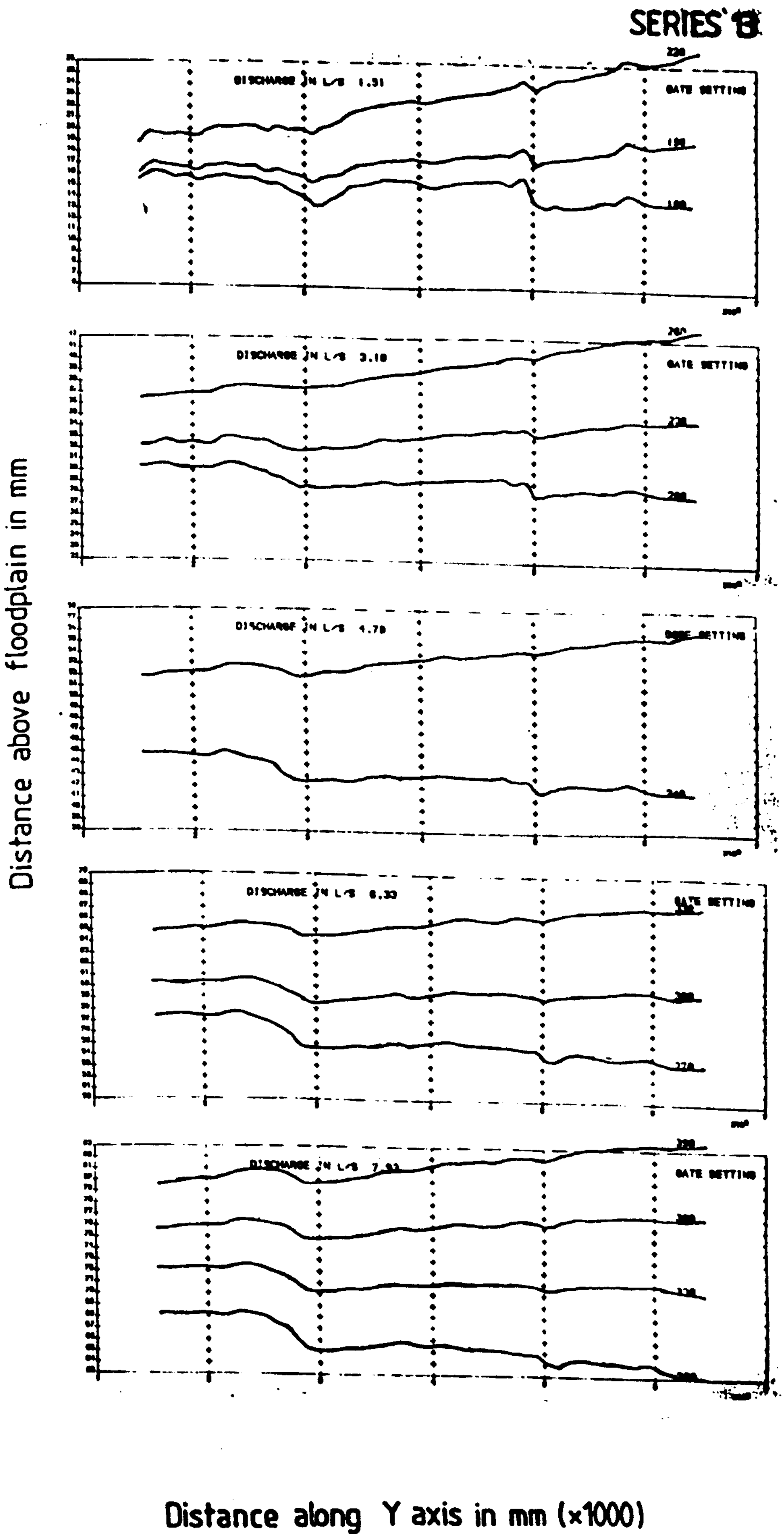
Distance along Y axis in mm (x1000)

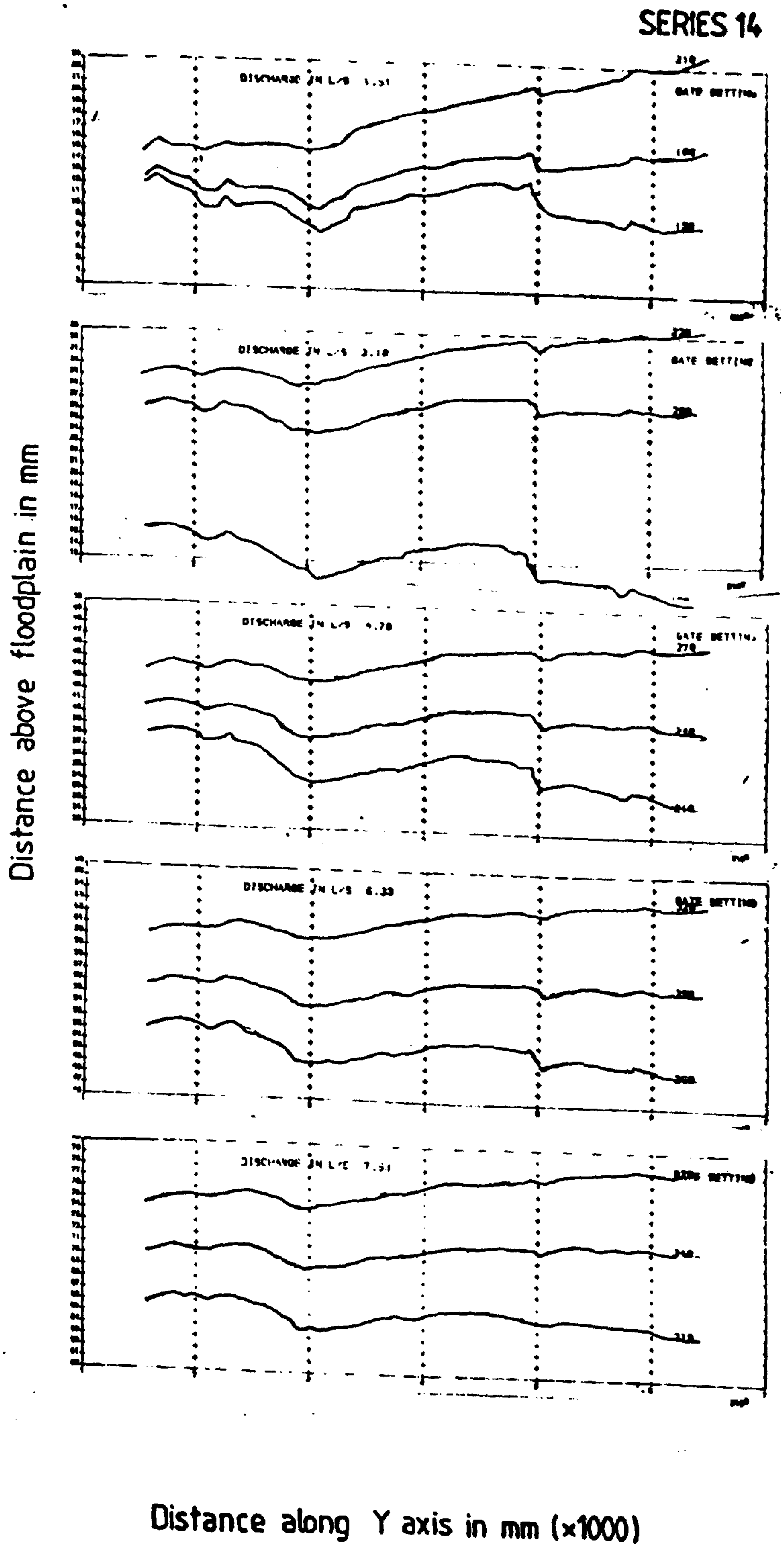
SERIES 10


DISCHARGE IN L/S 3.10
GATE SETTING
DISCHARGE IN L/S 4.70
GATE SETTING
DISCHARGE IN L/S 6.33
GATE SETTING
DISCHARGE IN L/S 7.93
GATE SETTING
DISCHARGE IN L/S 9.44
GATE SETTING
Distance above floodplain in mm
Distance along Y axis in mm (x1000)


SERIES 11
DISCHARGE IN L/S 3.10
GATE SETTING
250
220
190
DISCHARGE IN L/S 4.70
GATE SETTING
250
240
230
DISCHARGE IN L/S 6.33
GATE SETTING
310
290
DISCHARGE IN L/S 7.93
GATE SETTING
330
300
DISCHARGE IN L/S 9.44
GATE SETTING
360
330
300
Distance above floodplain in mm
Distance along Y axis in mm (x1000)


SERIES 12
DISCHARGE IN L/S 1.51
GATE SETTING
210
180
DISCHARGE IN L/S 3.10
GATE SETTING
220
190
DISCHARGE IN L/S 4.78
GATE SETTING
255
220
DISCHARGE IN L/S 6.33
GATE SETTING
290
260
DISCHARGE IN L/S 7.93
GATE SETTING
330
300
270
DISCHARGE IN L/S 9.44
GATE SETTING
330
300
270
Distance above floodplain in mm
Distance along Y axis in mm (x1000)


SERIES 'B'
DISCHARGE IN L/S 1.31
GATE SETTING
DISCHARGE IN L/S 3.10
GATE SETTING
DISCHARGE IN L/S 4.70
GATE SETTING
DISCHARGE IN L/S 6.33
GATE SETTING
DISCHARGE IN L/S 7.93
GATE SETTING
Distance above floodplain in mm
Distance along Y axis in mm (x1000)


SERIES 14
Distance above floodplain in mm
Distance along Y axis in mm (x1000)

SERIES 9
ROUGHNESS: F15 M6

DISCHARGE(L/S)	NORMAL DEPTH(MM)
1.51	17
3.10	30
4.78	43
6.33	50
7.93	57
9.44	63

SERIES 10
ROUGHNESS: F16 M6

DISCHARGE(L/S)	NORMAL DEPTH(MM)
3.10	31
4.78	43
6.33	51
7.93	62
9.44	70

SERIES 11
ROUGHNESS: F17 M6

DISCHARGE(L/S)	NORMAL DEPTH(MM)
3.10	30
4.78	42
6.33	53
7.93	61
9.44	71

SERIES 12
ROUGHNESS: F17 M6

DISCHARGE(L/S)	NORMAL DEPTH(MM)
0.4	0
1.51	16
3.10	30
4.78	41
6.33	50
7.93	56
9.44	64

SERIES 13
ROUGHNESS: F11 M6

DISCHARGE(L/S)	NORMAL DEPTH(MM)
.4	0
1.51	16
3.10	30
4.78	46
6.33	60
7.93	71

SERIES 14
ROUGHNESS: F11 M1

DISCHARGE(L/S)	NORMAL DEPTH(MM)
.4	0
1.51	13
3.10	26
4.78	42
6.33	57
7.93	71